State of Delaware
DELAWARE GEOLOGICAL SURVEY
Robert R. Jordan, State Geologist

REPORT OF INVESTIGATIONS NO. 63

AN EVALUATION OF SAND RESOURCES, ATLANTIC OFFSHORE, DELAWARE

by

Kimberly K. McKenna

Kelvin W. Ramsey

University of Delaware
Newark, Delaware

2002

State of Delaware
DELAWARE GEOLOGICAL SURVEY
Robert R. Jordan, State Geologist

REPORT OF INVESTIGATIONS NO. 63

AN EVALUATION OF SAND RESOURCES, ATLANTIC OFFSHORE, DELAWARE

by

Kimberly K. McKenna

Kelvin W. Ramsey

University of Delaware
Newark, Delaware

2002

CONTENTS

ILLUSTRATIONS

TABLES

APPENDICES

PLATE

AN EVALUATION OF SAND RESOURCES, ATLANTIC OFFSHORE, DELAWARE

Kimberly K. McKenna and Kelvin W. Ramsey

ABSTRACT

Lithologic logs from 268 vibracores taken from the Delaware Atlantic offshore were evaluated for sediment type and compatibility with historical beach sediment textures. A model of sand resource evaluation, known as "stack-unit mapping" (Kempton, 1981) was applied to all of the cores, and each core was labeled by its lithology in vertical sequence. The results are shown in detailed maps of the beach-quality sand resources offshore in state and federal waters. Results show significant quantities (approximately 54 million cubic yards) of excellent beach-quality sand sources within the three-mile state limit offshore Indian River Inlet, and within the Inner Platform and Detached Shoal Field geomorphic regions. In federal waters, sand is found on Fenwick Shoal Field and farther offshore Indian River Inlet on the Outer Platform (approximately 43.6 million cubic yards combined). Most of the beach-quality sand resources are believed to be reworked tidal delta deposits of a former Indian River Inlet during periods of lower sea level. Farther south, the resources are accumulations of recent surficial sands of the inner shelf (Detached Shoal Field and Fenwick Shoal Field) showing that the geomorphic region does influence sediment quality. This study found that paleochannels and bathymetry had no relationship to grain size. Multiple cut and fill episodes contributed to the diversity in grain sizes.

INTRODUCTION

Over the last ten years, the Delaware Geological Survey (DGS) has been compiling geologic data from offshore in state and federal waters. These data are used for interpretation of the offshore geology and the understanding of offshore sand resources. Sand is a natural resource sought after by those who manage the Delaware shoreline. It is used to build beaches for tourism and for protecting structures. Locating known sand resources, preferably as close as possible to the site needing the sand, is the goal of those managers as costs for offshore sand can be very high. The payoff, though, is a strong coastal tourism economy where visitors spend more than $573 million in beach trip expenditures, and beach community housing is estimated at $3.5 billion (Faucett Associates, 1998).

Delaware's Atlantic coast beaches are popular tourist destinations and as such, maintenance of the beaches is important for the economy of the state. In order to maintain wide, sandy beaches in the areas where beach width has been decreasing, beach replenishment has been implemented. From 1988 to 1998, over 4.1 million cubic yards of sand was dredged from some of the offshore borrow areas to nourish beaches in ten Delaware Atlantic coastal communities (R. D. Henry, 2001, personal communication). Some areas where potential good-quality sand is found are within former artillery firing ranges. The greater demand for sand for the eroding beaches of Rehoboth Beach, Dewey Beach, Bethany Beach/South Bethany, and Fenwick Island has prompted the Delaware Department of Natural Resources and Environmental Control (DNREC) and the U.S. Army Corps of Engineers (USACE) to intensify their search for quality sand. While most of the search has been within state waters, there is an interest for obtaining sand resources located farther offshore should the quality or amounts nearshore diminish over time. Since 1992, the Minerals Management Service (MMS) of the U. S. Department of the Interior and the DGS have worked together to determine the geologic framework and the distribution of sand resources in federal waters offshore Delaware.

The purpose of this study is to evaluate the existing vibracore database and identify potential sediment resources in state and federal waters of the Atlantic offshore. Two hundred and sixty-eight vibracores were extracted from the DGS core repository. A mapping tool known as "stack-unit mapping" was adapted from the Illinois Geological Survey (Kempton, 1981) and used to label lithologies based on the compatibility with native beach textural properties. This report presents the model results and provides approximate locations of potential beach-quality sand and aggregate resources.

Acknowledgments

This research was supported by the Minerals Management Service of the U. S. Department of the Interior, under MMS Agreement No. 14-35-0-001-30760. We thank Lillian T. Wang for producing some of the figures and for her help in organizing Plate 1. We appreciate the work of Robert D. Conkwright, Maryland Geological Survey, who provided the size analyses data for the DGS92 and DGS97 cores. Michael S. Carnivale, US Army Corps of Engineers, and W. Hank Stack, Duffield Associates, graciously provided reports and lithologic logs of the USACE cores. And, we are grateful for the core descriptions and computer database work provided by Marijke J. Reilly and Jennifer L. Gresh. Richard N. Benson, A. Scott Andres, and Wendy L. Carey provided reviews of the manuscript.

Previous Work

Previous geologic investigations of the Delaware coastal and offshore regions are listed in Table 1. The table provides a compilation of the major data sources from previous work that have been used in preparation of this report. These data include geophysical, core and bottom samples. When available, the vibracore log descriptions were used for this investigation of sand resources. Other sources concentrated on interpretations of major bathymetric features such as the shoal fields and their origin. The findings from some of the former studies are discussed in the appropriate sections of this report.

Table 1. References of previous work, geographic area covered, and data contained within the project area.

Reference	Geographic Area	Data Type
Moody, 1964	attached shoals	model, bathymetry
US ACE, 1966	general offshore	grab
Kraft, 1971	general onshore-offshore	cross section
Oostdam, 1971	Delaware River paleovalley	cores
Duane, et al., 1972	attached, detached shoals	bathymetry
Swift, et al., 1972	general offshore	bathymetry
Swift, 1973	Delaware River paleovalley	bathymetry
Sheridan, et al., 1974a,b	general offshore	cores, geophysics, cross section
US ACE, 1975	general offshore	cores
US ACE, 1976	general offshore, Hen and Chickens Shoal	cores
Belknap and Kraft, 1977	general offshore	radiocarbon dates, sea level
Twichell, et al., 1977	Delaware River paleovalley	geophysics
Field, 1979	detached shoals	cores
Field, et al., 1979	attached, detached shoals (MD)	cross section, radiocarbon dates, cores
Belknap and Kraft, 1981	general offshore	model, cross section, geophysics
Collins, 1982	Indian River Inlet ebb delta	cores
Belknap and Kraft, 1985	inner platform, attached shoals	cores, cross section
Terchunian, 1985	Hen and Chickens Shoal	cores, cross section
Underwood and Anders, 1987	detached shoals	cores
McBride and Moslow, 1991	attached, detached shoals	model
McGee, 1995	general offshore	cores, geophysics
US ACE, 1996	offshore Rehoboth and Dewey Beaches	cores
Woodward-Clyde, 1997	offshore Fenwick Island	cores
Duffield Associates, 1999, 2000	offshore Rehoboth/Dewey and Bethany/S. Bethany Beaches	cores
Williams, 1999	general offshore	cores, geophysics, cross section, radiocarbon dates

GEOLOGY

Geographic Setting

The Delaware Atlantic Coast stretches 25 miles (40 kilometers) from Cape Henlopen to the Delaware/Maryland border on Fenwick Island. Incorporated and unincorporated towns are interspersed with state-owned parks. Figure 1 shows the coastal and offshore quadrangles that cover the study area. The 7.5-minute offshore quadrangles were created for the DGS well location database and are not official U.S. Geological Survey (U.S.G.S.) quadrangles (Ramsey and Baxter, 1996). Offshore vibracores located within the unofficial quadrangles are labeled using the same process as wells and boreholes onshore and as those within official U.S.G.S. quadrangles (Talley and Windish, 1984).

In Delaware, beach replenishment has been a popular form of maintaining beaches damaged or threatened by erosion. The earliest projects were begun in the 1960s. The most recent beach replenishment projects have used sand from the shoreface and inner shelf and include the public beaches of Rehoboth Beach/Dewey Beach (over 1.4 million cubic yards) and Bethany Beach/South Bethany (approximately 3.0 million cubic yards) (U.S. Army Corps of Engineers, 1996, 1998). The beaches of Fenwick Island are scheduled for a replenishment project of more than 500,000 cubic yards (U. S. Army Corps of Engineers, 2000).

Geomorphic Features

The Delaware Coast consists of a typical headland, lagoon, barrier configuration (Figure 2) (Ramsey et al., 2000). A spit complex, Cape Henlopen, is located at the northern end of the coast. Major headlands are found at Rehoboth Beach, Bethany Beach, and South Bethany (Figure 1). Between the headlands, bay barriers separate the waters of the Atlantic Ocean from the waters of the coastal lagoons of Rehoboth Bay, Indian River Bay, and Little Assawoman Bay.

For the purposes of this study, offshore Delaware is defined as a triangular area bounded by the shoreline to the west, the eastward projection offshore of the Delaware-Maryland state line to the south, and a bathymetric low that is the paleovalley of the Delaware River to the east. The offshore is divided into the following areas based on bathymetric features (Figure 3):

- Delaware River Paleovalley
- Hen and Chickens Shoal
- Attached Shoal Field and Shoreface
- Inner Platform
- Outer Platform
- Detached Shoal Field
- Fenwick Shoal Field

The Delaware River paleovalley is a distinct baythymetric low that trends from northwest to southeast from the mouth of Delaware Bay to the continental shelf. It is flanked on the northeast and southwest by bathymetric highs and is defined as a low with depths greater than 70 ft (all depths are presented below sea level) with maximum depths up to 150 ft. Most of the paleovalley is at depths of 70 to 105 ft within the area of this study.

Two attached shoal fields, one to the south of Dewey Beach and the other to the north of Bethany Beach, rest on the Inner Platform. The dividing line between these fields is the Indian River Inlet. These attached shoals range from 10 to 30 ft water depth and have a distinctive finger-like pattern with an orientation of southwest to northeast at an angle of about 45° to the shoreline.

The Inner Platform extends the entire length of the Atlantic Coast of Delaware. It is generally flat with depths between 20 and 40 ft below sea level, with much of it between 30 and 40 ft. The platform gently slopes to the east-southeast. The eastern limit of the platform is the 40-ft contour which trends north-south parallel to the present shoreline. The 40-ft line is at a bathymetric break where depths drop from 35 ft on the west to about 50 ft to the east on the Outer Platform. The Detached Shoal Field rests on the platform astride the offshore projection of the Delaware/Maryland state boundary.

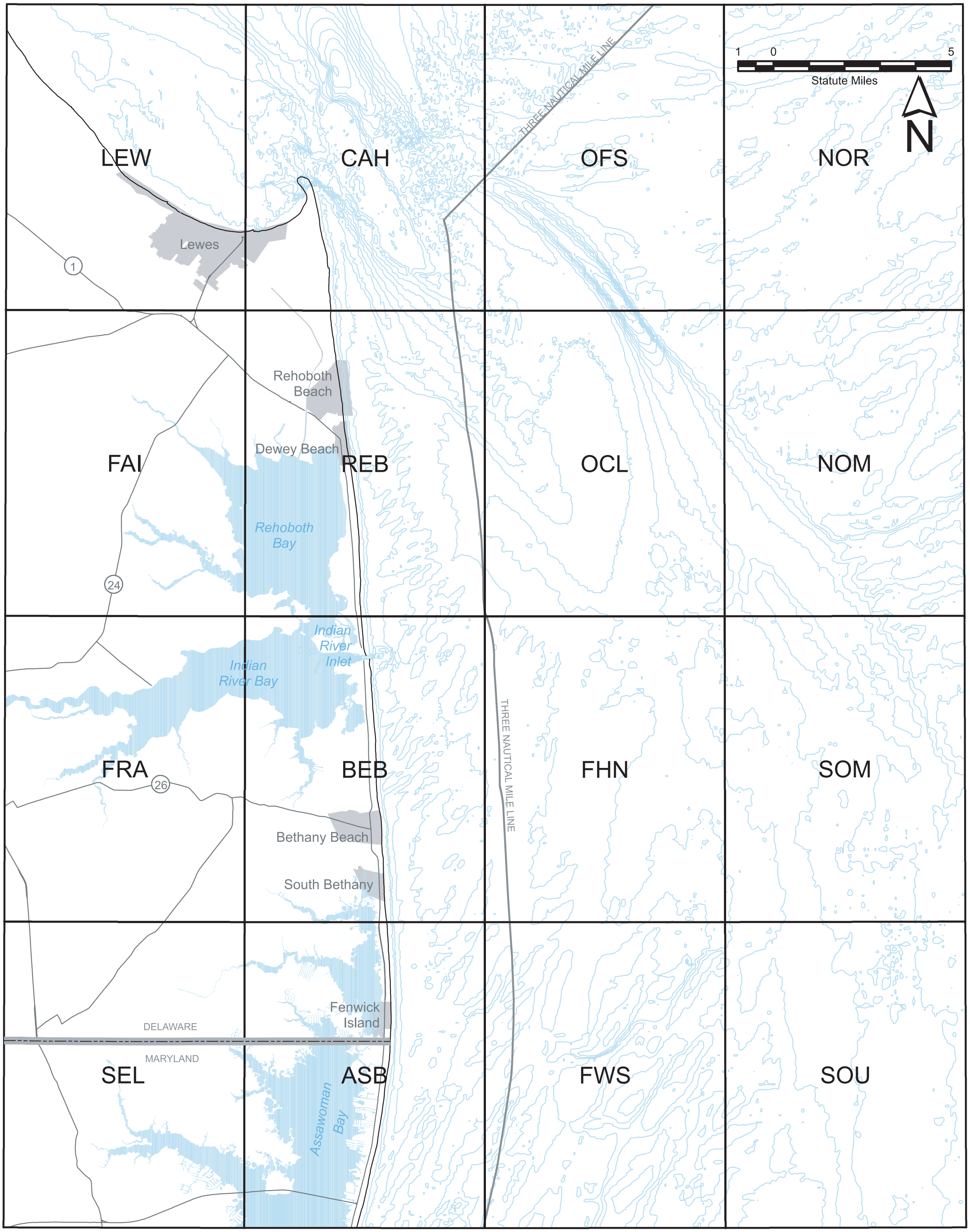

Figure 1. Geographic and cultural features of the study area. Solid boxes indicate outlines of the 7.5-minute topographic quadrangles that cover the study area. Those completely offshore are from Ramsey and Baxter (1996) and are not "official" U.S.G.S. quadrangle maps. Quadrangles include Lewes (LEW), Cape Henlopen (CAH), Overfall Shoal (OFS), North (NOR), Fairmount (FAI), Rehoboth Beach (REB), Old Channel (OCL), North Middle (NOM), Frankford (FRA), Bethany Beach (BEB), Fish Haven (FHN), South Middle (SOM), Selbyville (SEL), Assawoman Bay (ASB), Fenwick Shoal (FWS), and South (SOU). For detailed information on bathymetry and base map source, please refer to Plate 1 for this and all other map figures.

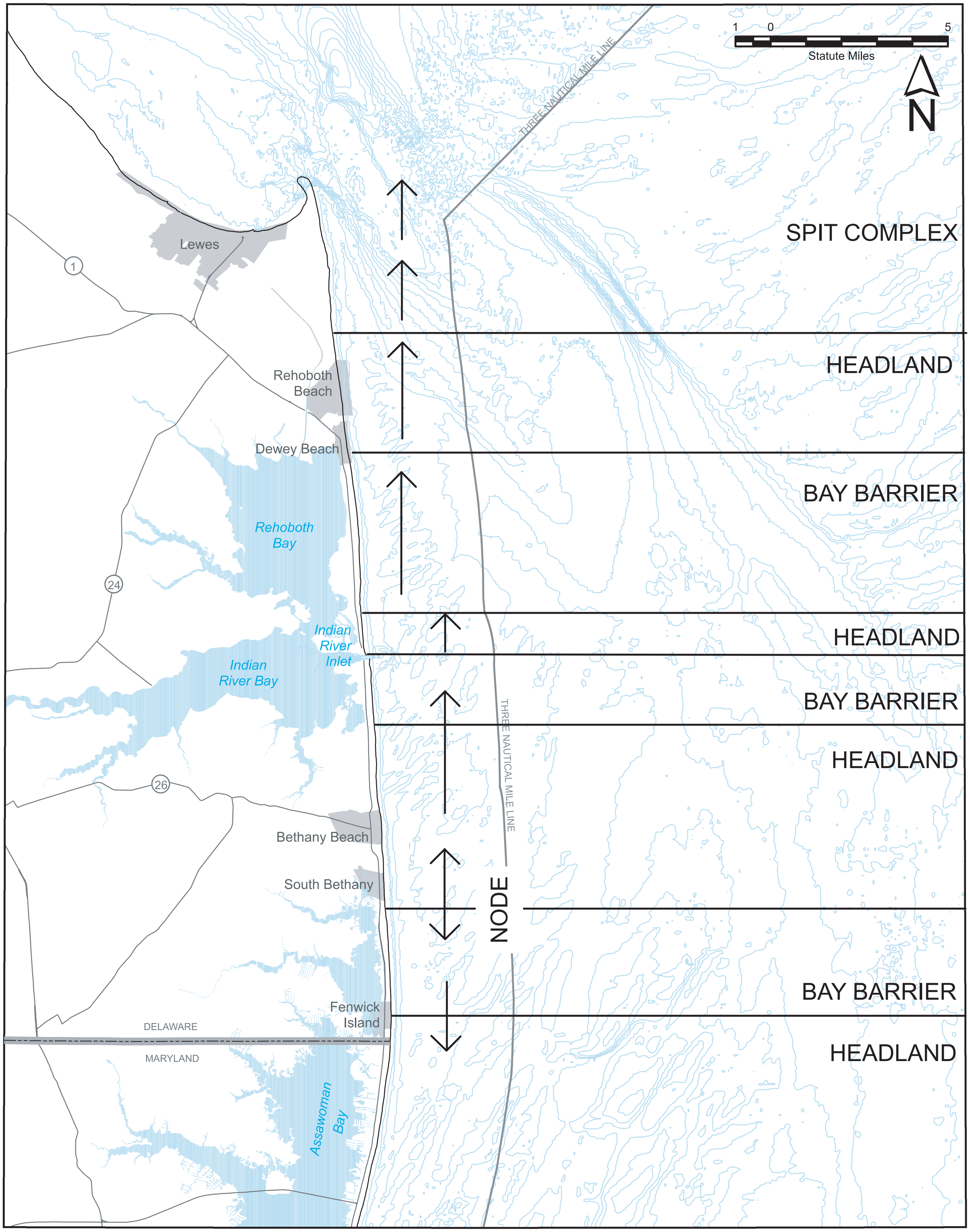

Figure 2. Physiographic regions of the Delaware coast (modified from Ramsey et al., 2000). Arrows indicate the general direction of the littoral current.

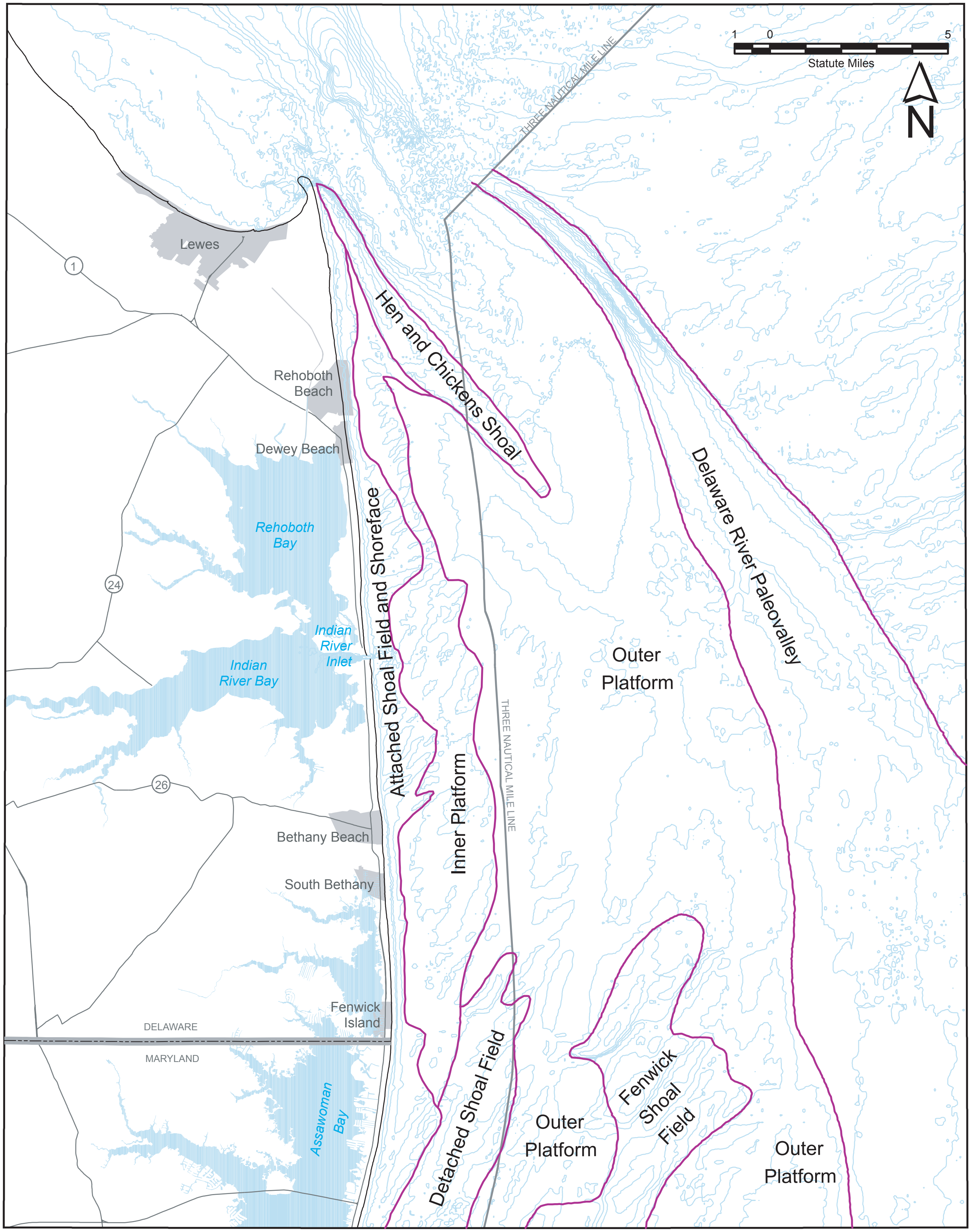

Figure 3. Geomorphic regions offshore Delaware.

The Outer Platform is a relatively flat area gently sloping to the east-southeast with depths ranging between 40 and 70 ft. It is marked to the east by the western edge of the Delaware River Paleovalley. The Fenwick Shoal Field rests upon the platform seaward of the Detached Shoal Field.

The Detached Shoal Field is a patchwork of shoals offshore Fenwick Island with depths ranging between 20 and 30 ft. This field extends to the south and includes shoal areas off Ocean City, Maryland. The shoals are elongate with an orientation much like that of the Attached Shoal Field (trending northeast-southwest at 45°to the shoreline).

The Fenwick Shoal Field lies seaward of the Detached Shoal Field and includes one large shoal, Fenwick Shoal, and two smaller shoals to the south off Maryland, Weaver Shoal and Isle of Wight Shoal. Depths range between 14 and 30 ft on the shoals with depths on the platform around the shoals ranging between 45 and 65 ft. The shoals are somewhat elongate with a long axis trending northeast-southwest at about 45° to the shoreline, roughly parallel to those in the Detached Shoal Field.

Geologic Framework

No regional stratigraphic synthesis of near-bottom stratigraphic units has been published for offshore Delaware. Most previous work focused on the Holocene part of the section, bathymetric features, site-specific studies, or models of process or stratigraphic completeness related to transgression and regression (Table 1). Two separate methods have been used to establish offshore stratigraphy. The first is a lithostratigraphic method that extends onshore stratigraphic units offshore. The second uses cores and seismic data to establish a stratigraphy based on seismic units related to observations of cores.

Lithostratigraphic Units

Ramsey (1999b) published a cross section of the Atlantic Coast of Delaware from Cape Henlopen to Fenwick Island. This cross section shows three stratigraphic units: the Beaverdam and Omar formations and Holocene deposits. One can assume that the Beaverdam and Omar lithostratigraphic units had some extent to the east of the present shoreline and are, at most, gently dipping (<2°). They should have either been removed by subsequent erosion, exposed on the present sea floor, or covered by late Pleistocene to Holocene deposits.

The Beaverdam Formation is of latest Miocene to Late Pliocene age and represents a fluvial to estuarine depositional environment (Benson, 1990; Groot et al., 1990). It consists of fine to coarse sand with interbeds of fine silty sand to sandy and clayey silt with scattered beds of organic material. Gravel and pebbly beds are common. In the coastal areas of Delaware, the Beaverdam has a characteristic fining-upward signature on gamma logs (Benson, 1990; Andres, 1986).

The Omar Formation is of middle to late Pleistocene age (Groot et al., 1990; Ramsey, 1997). It was deposited in several distinct transgressive events associated with rising sea level and high sea stands. The Omar in coastal Delaware is a gray clayey sand to sandy silt that contains scattered shelly and organic-rich beds containing plant fragments. Scattered beds of fine sand and silty fine sand are common. Less common are thin beds of medium to coarse sand (Benson, 1990). The Omar was deposited in lagoonal, tidal delta, marsh, and barrier environments, much like that of the present coastal system.

Holocene deposits are not assigned to a formal stratigraphic unit. They consist of fine to coarse sand, sandy to clayey silt, silty clay, and organic-rich beds with abundant plant fragments. These sediments were deposited during the rise of sea level in a transgressive barrier-lagoon system (John, 1977; Kraft and John, 1976; Chrzastowski, 1986; Kraft et al., 1987). Numerous radiocarbon dates document the Holocene age of these deposits (Ramsey and Baxter, 1996).

These three stratigraphic units have unconformable stratigraphic relationships as mapped in onshore locations (Ramsey, 1999b). In many places the lithologies and degree of compaction or weathering allow them to be readily distinguishable from each other. Where similar lithologies from the units rest upon each other (sand on sand or mud on mud), differentiating them is not always possible. Fossil content (primarily palynomorphs) aids in differentiating them (Groot and Jordan, 1999) but only in unoxidized fine to very fine sands, clayey silts, and silty clays. On the bases of core and seismic data, all three stratigraphic units can be mapped offshore and in further discussion will be related to seismic and lithologic units as defined from offshore data.

Seismic Stratigraphic Units

Figure 4 shows selected lines of seismic data that relate to sand resources offshore. In August 1992, 325 km of analog single-channel 3.5 kHz seismic reflection profiles were collected on the *RV Discovery* of the Maryland Department of Natural Resources (Figure 4). These seismic data were used to select the core sites for core collected in 1992 and in 1997. Williams (1999) built upon the work of Field (1979) and Toscano et al., (1989) and used the 1992 seismic (shown in green) and core data to develop an interpretation of the geologic framework of the study area on the basis of the seismic data.

Williams (1999) noted five stratigraphic units, A-E, interpreted from the seismic profiles with additional data from core sediment lithology, and dating of the units by amino acid racemization analyses, radiocarbon dates, and some palynologic work. These units are summarized in Table 2. Rarely, if ever, are the seismic units found stacked upon each other. Relative stratigraphic position of the units was determined by examination of the seismic data over the entire study area and identification of cross-cutting and vertical relationships (Williams, 1999).

Relationship of Lithostratigraphic to Seismic Units

The relationship of the lithostratigraphic units to seismic units is the subject of ongoing investigations related to the stratigraphic framework of the Delaware offshore. Preliminary analyses suggest that Units A and B do not have onshore counterparts other than that they are nearshore and shelf time-equivalents to Holocene deposits that make up the present barrier-lagoon system. Unit C may have onshore equivalents in the thin coarse sands and gravels that are

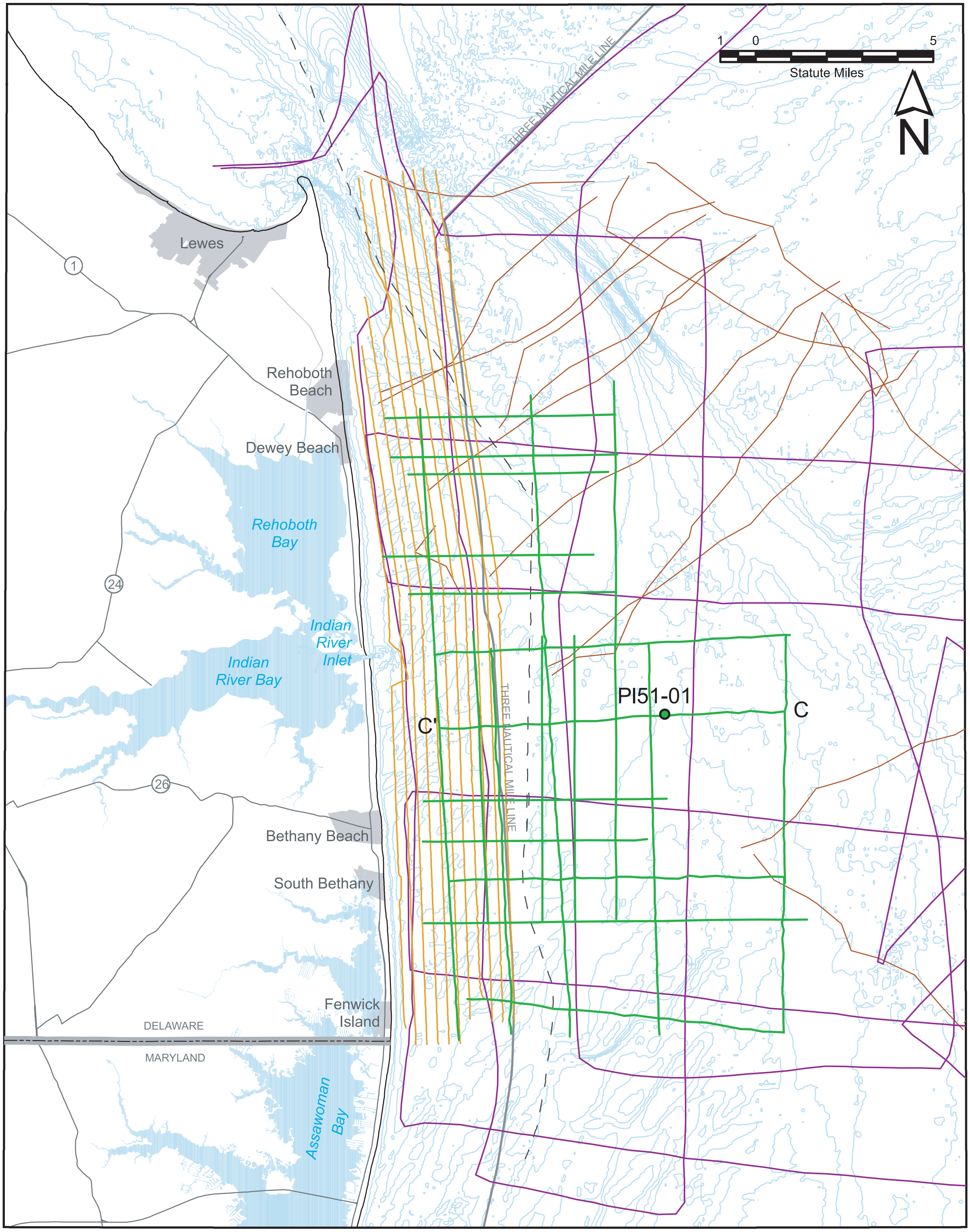

Figure 4. Locations of shallow seismic lines in the Atlantic offshore Delaware. The data are from Belknap, unpublished data (brown); Benson et al., 1986 (grey dash); Maryland Geological Survey, unpublished data and Williams, 1999 (green); McGee, 1995 (orange); and University of Delaware Department of Geology, unpublished data (purple). Track line C-C' is shown as referrence for Figure 5.

Table 2. Summary of seismic stratigraphic units (modified from Williams, 1999). Maryland (MD) units are from Toscano et al. (1989).

Seismic Unit	Description	Age	^{18}O Stage	Equivalent MD offshore unit	Onshore Equivalent Unit
A	Modern shelf sand. Fine to very coarse. May contain gravelly, silty, or clayey zones.	Holocene	1	Q5	Holocene
B	Nearshore deposits. Fine to coarse sand, muddy sand, and sandy mud.	Holocene	1	Q4	Holocene
C	Fluvial to estuarine. Coarse to gravel. Commonly found within incised paleovalleys	Early Holocene-Late Pleistocene	2	Q3	Omar Formation
D	Lagoonal/estuarine muds. Contain thin silt or fine sand laminae. Also includes fine to very coarse sands similar to Unit A	Pleistocene	5	Q2	Omar Formation
E	Heterogeneous unit distinctive in seismic profiles as older than above units.	Pleistocene-Pliocene	7 and older	Q1	Beaverdam & Omar formations

found at the base of the paleovalleys filled with Holocene sediments (Chrzastowski, 1986). In other places Unit C does not have an age equivalent onshore specifically if it occupies paleovalleys found only offshore that developed during oxygen isotope stage 4 and were filled during a high-stand of stage 3 (Williams, 1999). Unit D most likely represents the offshore equivalent of the Omar Formation found onshore. Unit E is probably in part equivalent to the Omar Formation and in part the Beaverdam Formation (primarily in the study area offshore Fenwick Island). Williams (1999) describes Units A, C, D, and E as possible sources of sand. Figure 5 shows a sample seismic line from Williams (1999) and the interpreted lithologic units from Core No. Pl51-01.

Williams (1999) also identified paleovalleys from the seismic data. These valleys represent multiple cut and fill episodes that have occurred during the Pleistocene and Holocene. Figure 6 shows the locations of the paleovalleys. Most of the paleovalleys are interpreted to have been cut and filled during the Holocene, or cut and filled during the Pleistocene and reoccupied and filled during the Holocene. The exception is a system of paleovalleys that extends offshore from Bethany Beach. These paleovalleys are interpreted to be of Pleistocene age and filled with sediments equivalent to the Omar Formation. If similar stratigraphic relationships hold from those found onshore (Ramsey, 1999b), then the area to the south of this paleovalley system likely has the Beaverdam Formation at or near the seafloor. Core data from the area appear to confirm this interpretation.

METHODS

Historical Beach Textures

Ramsey (1999a) conducted a study of historical (pre-replenishment) beach sand textures along Delaware's Atlantic Coast. The coast was divided into 40 one-kilometer- long segments. All of the textural data from within each segment were collected and averaged for each segment. In general, sediments become coarser (although minor) from Cape Henlopen to the headland at the Indian River Inlet (north to south), and from the southern headland at Fenwick Island to the Indian River Inlet (south to north) (Figure 2). Sorting increases from north to south.

The direction of the longshore transport of sediments diverges at a point (identified as NODE) between Bethany Beach and Fenwick Island (Figure 2). This nodal point migrates between those shorefront communities and appears to have little effect on the sediment size, nor does Indian River Inlet have any dramatic effect on sediment grain size and sorting. The sands at the end of the transport system at Cape Henlopen are found to be finer-grained and slightly less sorted than those sediments to the south.

On the basis of the 1988 study, Ramsey (1999a) recommended that sand placed on Delaware's beaches have the following textural criteria: mean grain size between 1.5 to 0.5 phi (0.35 to 1.42 mm), 0.5 phi or less sorting, and a negative skewness (desirable, but not necessary). These criteria were based on the range of historical textures from beach sediment samples that were obtained from studies spanning 55 years and included variations in beach locations and times of year. It was assumed that the historical or natural textures would be in balance with the wave and wind climate for the coast and the sediment source. Textures much finer than those historically found on the beach would be more likely to be transported out of the nearshore during high wave events that would not otherwise have affected the beach, and finer sediments could be drastically removed during storm events. Textures much coarser than those found on the beaches may lead to oversteepening of the beach and may create some hazards for recreational use. Komar (1998) concludes that there is still a need for research in the behavior of sediment particles by waves and currents because some studies have shown that grain density has more influence than sediment size on beach fill longevity (Eitner, 1996). In general, sediment sources for beach replenishment projects are based on the availability and cost of transporting the sediment to the beaches in need.

Coring, Sampling, and Lab Work

Two hundred and sixty eight vibracore logs from the shoreface and inner continental shelf were extracted from the Delaware Geological Survey (DGS) Core and Sample Repository database (locations on Plate 1). This database includes all records of vibracores published in the reports noted in Table 1, the DGS92 and DGS97 data (core locations chosen for evaluating sand resources), and any unpublished DGS and USACE vibracore data. Lengths of the cores range from 0.25 ft to 120.5 ft. Cores were taken in water depths of 0 to 142 ft. The log descriptions for all cores were evaluated for sediment type, grain size, layer thickness, and number of layers. Plate 1 shows the locations of all vibracores in the offshore database and Appendix A provides the supporting information for them.

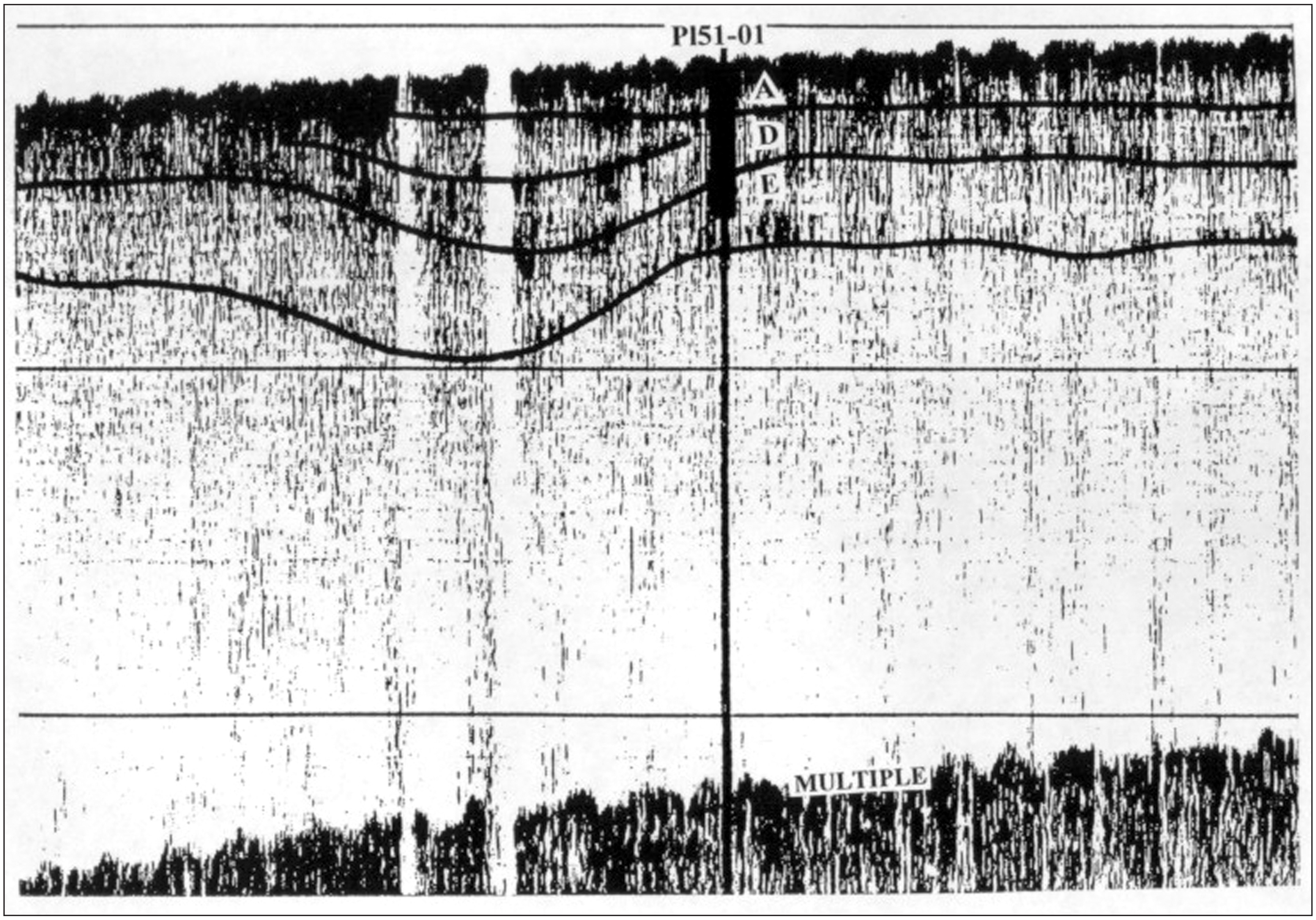

Figure 5. Interpretation of seismic line C-C' (Figure 4) at trackmark 11 by Williams (1999) showing Core No. Pl51-01 and labeled units described in Table 2. Horizontal distance is approximately 919 ft and depth to the multiple is approximately 65 ft.

DGS92 and DGS97 Vibracores

The DGS92 and DGS97 datasets total 76 vibracores and were obtained through a cooperative program with the MMS. The grain size information from them are used in the analysis for this report. The locations of the coring sites were chosen where seismic data indicated that a 20-ft vibracore would penetrate through Holocene-age sediments and for maximizing the probability of finding beach-quality sand.

Each core was split in half lengthwise using a circular saw, and one half was wrapped and archived in the DGS Core and Sample Repository. The other half of each core was described, based on a visual review of the core, for lithology, mineralogy, color, and significant features (bioorganic and sedimentary structures) and sampled at half-foot intervals for later texture analyses. In most cases the samples contain sand. Muddy segments within the cores were not sampled and run for sediment texture because they were immediately identified as not suitable for beach replenishment material. Isolated peats and organic materials were sampled for radiocarbon dating from two cores (Qk33-01 and Ql51-02)[1] and shells were obtained for amino acid racemization analyses.

Following extraction from the core, the samples were dried, split, weighed, and washed through 2 mm (-1ϕ) and 0.062 mm (4ϕ) mesh sieves in order to separate the sand fraction from the gravel (coarser than –1ϕ) and mud (finer than 4ϕ) fractions. After drying, the sand fractions were split and weighed and packaged for delivery to the Maryland Geological Survey (MGS) where grain size analyses were conducted using a rapid sediment analyzer (RSA) (Maryland Geological Survey, 1998). Peat and organic material were sent to Beta Analytic in Miami, Florida, for radiocarbon dating, and samples of mud were processed at the DGS for palynomorph analyses (Ramsey and McKenna, 1999).

The weight percentages of the gravel, sand, and mud (silt + clay) fractions of the sediment samples from the cores were calculated. Percentages from all the samples from a particular core were plotted on a triangular diagram as a visual method to determine the potential of a particular core site for beach replenishment material. The data are somewhat biased in that only sand samples were collected from the cores. A few cores do have sands that have a fine (mud) component in them (some with greater than 50% mud) that would preclude them from being considered further as

[1] Radiocarbon data are accessible through the DGS Data Repository located under "Geology," and core descriptions, textural analyses, and triangular diagrams are accessible under "Mineral Resources" on the DGS web page at http://www.udel.edu/dgs.

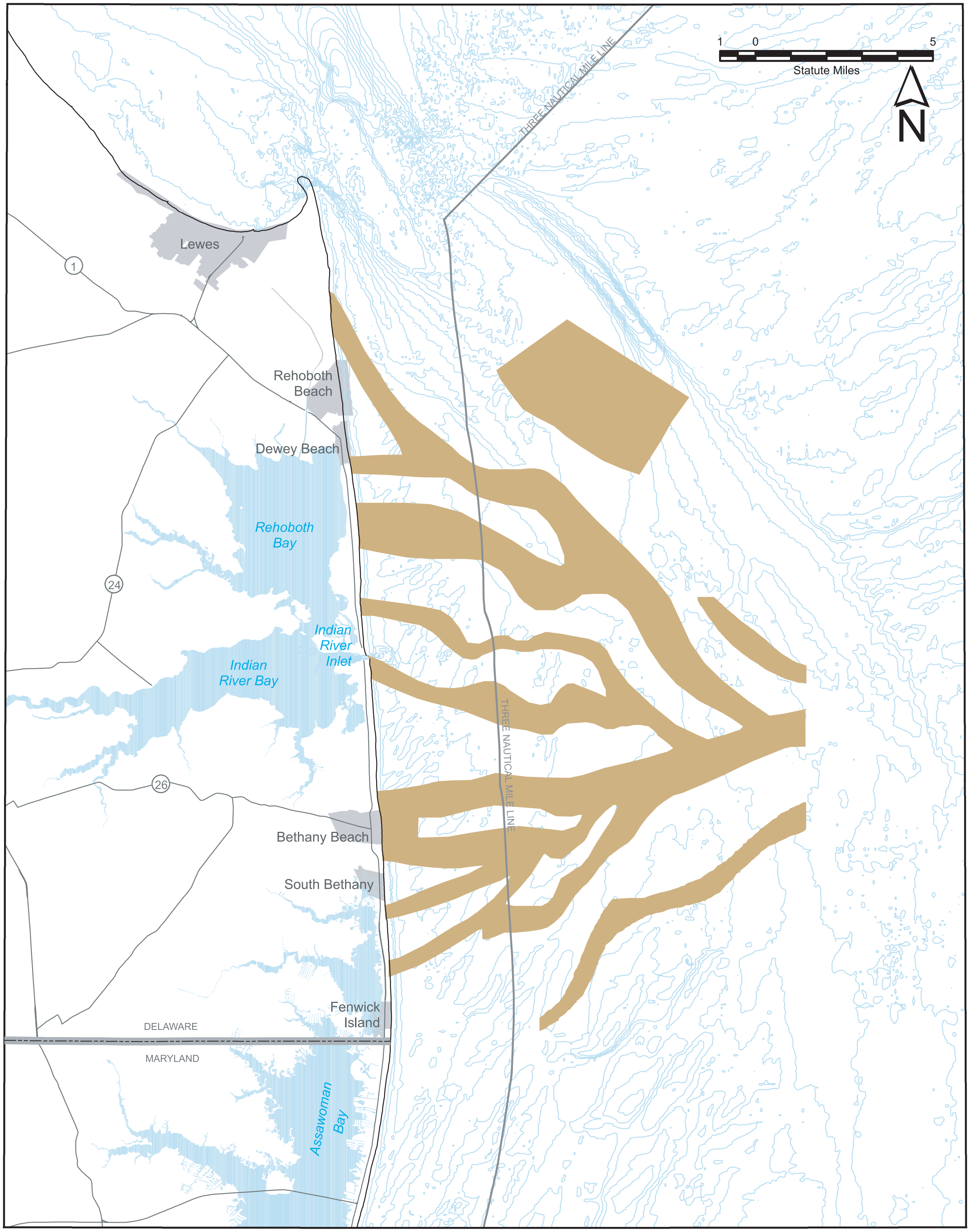

Figure 6. Paleovalley channels as interpreted by Williams (1999).

potential sand resource materials. Likewise, very few cores that have a significant gravel component were sampled for size analysis but visual gravel sections were noted in the lithologic description. The cores containing the gravel may indicate potential coarse aggregate resources. The potential for aggregate sites will be discussed later.

Application of Stack-Unit Mapping and GIS

This study uses a mapping tool known as "stack-unit mapping" to show geologic units in their vertical occurrence to a specific depth or boundary (Kempton, 1981). Developed by the Illinois Geological Survey, this method has been used to evaluate a variety of land-use issues related to mineral and water resources in Illinois (Berg et al., 1984; Kempton and Cartwright, 1984) and South Carolina (Rine et al., 1999) to ground-water recharge potential in the Atlantic Coastal Plain of Delaware (Andres, 1991). Here, the stack-unit mapping method was used to determine the suitability of offshore sediments for beach replenishment along the Delaware Atlantic shoreline. The stack-unit labels were used to produce interpretive maps of the sediments below the ocean surface that enabled us to better quantify sand resources.

The lithologic information from each core was logged into a database and included in a geographic information system data layer that was used to provide maps of the core locations within the offshore coordinate system. User-defined polygons surrounding cores with similar lithologies were created in the geographic information system and combined with five- and ten-foot thicknesses to obtain estimated volumes of the sediment resources.

Classification of Materials and Sediment Textures

Sediment textural properties are available for many of the offshore cores and were compared with visual core descriptions to determine the lithologic category for each core. Where textural analyses were available, the lithologic rating was assigned based on the analyses. In some cores, the grain size data were not available, and the lithologic rating was determined using the visual description of a core.

Table 3 shows the five lithologic rating and four resource rating units that were used to describe the cores. The categories were modified from Andres (1991) to include gravel. Gravel was established as a category for determining potential aggregate sources.

The lithologic units for each core log were evaluated and assigned a lithologic category symbol (G, S, L, M, or gS) based on the grain size description and textural analyses, if available (Table 4). For example, the most compatible lithologic category to the Delaware beaches is S, medium to coarse sand (2ϕ to –1ϕ) and containing up to ten percent of fine sand, silt, or gravel.

Table 3. Definitions of lithologic and resource rating symbols (modified from Andres, 1991).

Lithologic Rating Units

Lithologic Category Symbols

G = Gravel (>2.00 mm or –1.0 to –6.0 phi) with 0 to 10% silt or sand

S = Sand (2.0 to –1.0 phi) medium to very coarse with 0 to 10% silt or gravel

L = Fine or Silty Sand (4.0 to 2.0 phi) very fine to fine with 0 to 35% silt

M = Mud (>4.0 phi) coarse silt and finer material

gS = 10 to 50% gravel in sand matrix

Thickness Category Symbols

0 to < 5 ft = lower case*	21 to 25 ft = 25
5 to 10 ft = 10	26 to 30 ft = 30
11 to 15 ft = 15	31 to 35 ft = 35
16 to 20 ft = 20	36 to 40 ft = 40

*Lithologies with a total thickness of less than 2 ft may be combined with another lithologic category. Lower case letters imply a thickness of less than 5 ft.

Resource Rating Units

EXCELLENT (E)
Cores with sediments at top: >10S; ≥ 5S followed by ≥ 5gS; <5s followed by ≥ 10gS; ≥ 5gS followed by ≥ 5S; ≤ 2gS followed by ≥ 10S

GOOD (G)
Cores with sediments at top: between 10S and 5S; ≤ 5gS followed by ≥ 5S; ≥ 5gS

FAIR (F)
Cores with sediments at top: ≥ 5L; between 2s and 5s, l, or g; ≤ 5gS followed by l or m; <2m followed by 10S or 10L; <2s followed by >5L

POOR (P)
Cores with sediments at top: <2 feet thick; ≥ 2m; <2s followed by >5M; <5L followed by 10M

Each unit was then measured in feet and assigned a thickness symbol (0 to 5, 10, 15, 20, 25, or 30). For those cores where a lithologic section was less than five feet, a lower-case letter, g, s, l, or m, was assigned along with the thickness in one-foot increments (Appendix B). In the lithologic rating description for the cores with less than five feet of a particular lithology, a backslash separates the top few feet from the rest of the description. For example, core Pk32-02 (DGS97-53) was assigned a lithologic rating of 3s/5gS 10S. That means that the uppermost three feet contain beach-quality sand followed below by five feet of gravelly sand, and ten feet of sand (Figure 7). The lithologic description allows a resource evaluator to determine immediately the quality of sediment within the first five feet of the subsurface. After the first five feet, the ratings are assigned in five-foot increments (Table 3).

In the few cores where the textural analyses statistically showed gravel in amounts between 10 and 50 percent in a fine sand or silt matrix, a lower case letter and parentheses, g, precedes the dominant or matrix lithology which in all cases is S. The gS lithologic rating was assigned to gravelly sections two-feet thick or greater (Figure 7, Appendix B).

Resource Ratings

The criteria for determining the resource potential (E, G, F, or P) include the suitability or compatibility of the sediments with the native beach textural composite, the thick-

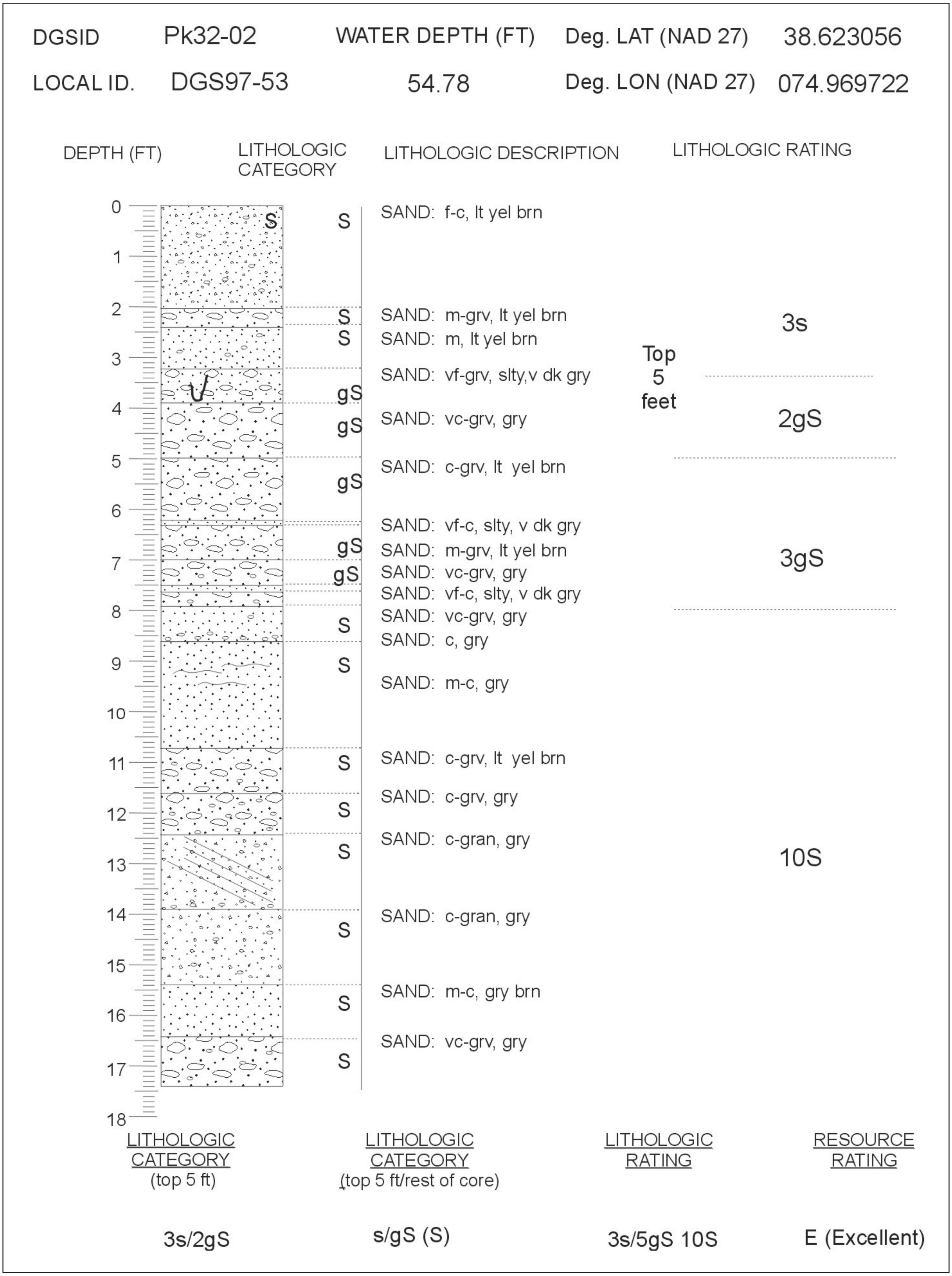

Figure 7. Resource rating for Core No. Pk32-02.

ness of the unit, and its depth below the sea floor surface. Sites with excellent (E) or good (G) ratings are considered to be potential sources of beach quality sand. Those with fair (F) ratings are considered marginal sources either because the sand is finer than that of native beach sand, or contains too much silt. Sites with poor (P) ratings should not be considered as sand sources.

Thickness, lithologic rating, and ultimately the resource rating are dependent upon the spatial relationships of the sedimentary units within a core. The most important section of a core is the upper five feet because five feet is the minimum amount of sediment that can be economically extracted by a hopper dredge. When labeling the lithologic category, the upper five feet was separated from the lithologies below to show the type of sediment that is available from the seafloor surface. This allows a resource evaluator to quickly assess the sediment type and recoverability of the sediment source. Those cores with between five and ten feet of sand (S) from the top of the core were assessed a good (G) resource rating, and cores with greater than ten feet of sand (S) from the top of the core were rated excellent (E) (Table 3).

An example of an excellent (E) core is Pk32-02 (DGS97-53) (Figure 7). It contains predominantly sand and small amounts of gravel throughout the length of the core (Appendixes A and B).

Figure 8 shows Core No. Pj23-01 (KHV-4) and its lithologic and resource ratings. The core was assigned a good (G) resource rating because the core contains six feet of beach-quality sand available for dredging even though the next lithologic section below is mud. The clayey sand located from ten to eleven feet was incorporated into the mud (M) category because it was less than two feet thick and contained clay. Here, the top five feet of sand makes this a good resource.

An example of a fair (F) rating is core Ok52-01 (DGS97-26) (Figure 9) from the outer platform near the southern tip of Hen and Chickens Shoal. It is mostly composed of fine sand with a mean grain size of 2.67ϕ; too fine for beach replenishment along the Delaware Atlantic shoreline (Appendixes A and B).

Core Qk33-01 (DGS97-58) (Figure 10) represents a poor (P)-rated core and is located on the outer platform approximately three miles offshore Bethany Beach. This core is composed of mostly silt and clay and is undesirable as beach replenishment material (Appendixes A and B).

RESULTS

Sediment Textures

Table 4 is a summary of the RSA analyses from each of the DGS92 and DGS97 cores. The statistics presented in Table 4 are averages of the samples analyzed from each core. In some cases, the samples may be from the top and the bottom of the core with an intervening muddy sample in the middle. As discussed previously, samples of mud interbeds are not included. A core that has eight or more samples is considered to contain predominately sand for the entire length of the core (if maximum penetration of 20 feet was reached). Core length is provided in Table 4. Where only one or two samples are indicated, either the core penetration was shallow or the core contained primarily mud with sand present only at the top of the core. Individual samples plotted on a gravel/sand/mud ternary diagram (Figure 11) show that the majority of cores contain sand-size material (4ϕ to -1ϕ), although this partially reflects a bias in the sampling methods.

Stack-Unit Maps

An initial test for using the stack-unit mapping method was conducted using core data from Hen and Chickens Shoal, considered as a sand source for beach replenishment (McKenna, 2000). The goal of the test was to determine the location, depth, thickness, and areal extent of compatible sand. The analysis showed that the sediments are too fine for beach replenishment as most of the cores were assigned a fair (F) resource rating. Only two cores (Oj24-02 and Oj33-01) located on the flanks of the shoal, contain beach-quality sand (Plate 1).

The stack-unit mapping exercise was continued for the rest of the Delaware offshore. Figure 12 shows the percentages of each resource rating by core when compared to the entire database. The majority of cores (40 percent) fall within the fair (F) resource rating. However, the excellent (E) and good (G) categories comprise 43 percent of the cores. This high percentage of beach-quality cores can be attributed to selecting coring locations using information and interpretations from former studies of the Delaware offshore.

Distribution of Sand and Aggregate Resources

On the basis of the data available, four significant excellent (E) or good (G) sand resource areas in federal waters and twelve in state waters were identified. Locations of the cores in the DGS offshore database are shown in Plate 1 with the applicable resource ratings and digitized polygons of resource groupings of excellent (E) and good (G) core locations. Both excellent (E) and good (G) groupings contain beach-quality sand, but what separates the two categories is the thickness of sand (S) measured from the top of the core. Most of the excellent (E) groupings tend to occur offshore Indian River Inlet (around cores Pj45-01 and Pk42-01) and southward (around cores Rk31-03 and Rk35-02) in both state and federal waters. These areas could be exploited for replenishing the Bethany Beach/South Bethany and Fenwick Island beaches. Northward, though, in the area of Hen and Chickens Shoal (around core Oj24-03), the sediment is finer than the native beach sand of Rehoboth Beach and Dewey Beach and no digitized polygons of the resource grouping are provided because the cores were assigned fair (F) resource ratings.

Resource Locations and Volumes

Resources in Federal Waters

In federal waters, two potential sand resource areas are found offshore Indian River Inlet and on Fenwick Shoal (Plate 1). The area off Indian River Inlet is interpreted to be composed of former ebb and flood tidal shoal and delta deposits and reworked Holocene barrier complex and inner shelf deposits. It represents the migration of the shoreline with the rise and fall of sea level during several glacial and interglacial periods (Kraft and John, 1979; Williams, 1999).

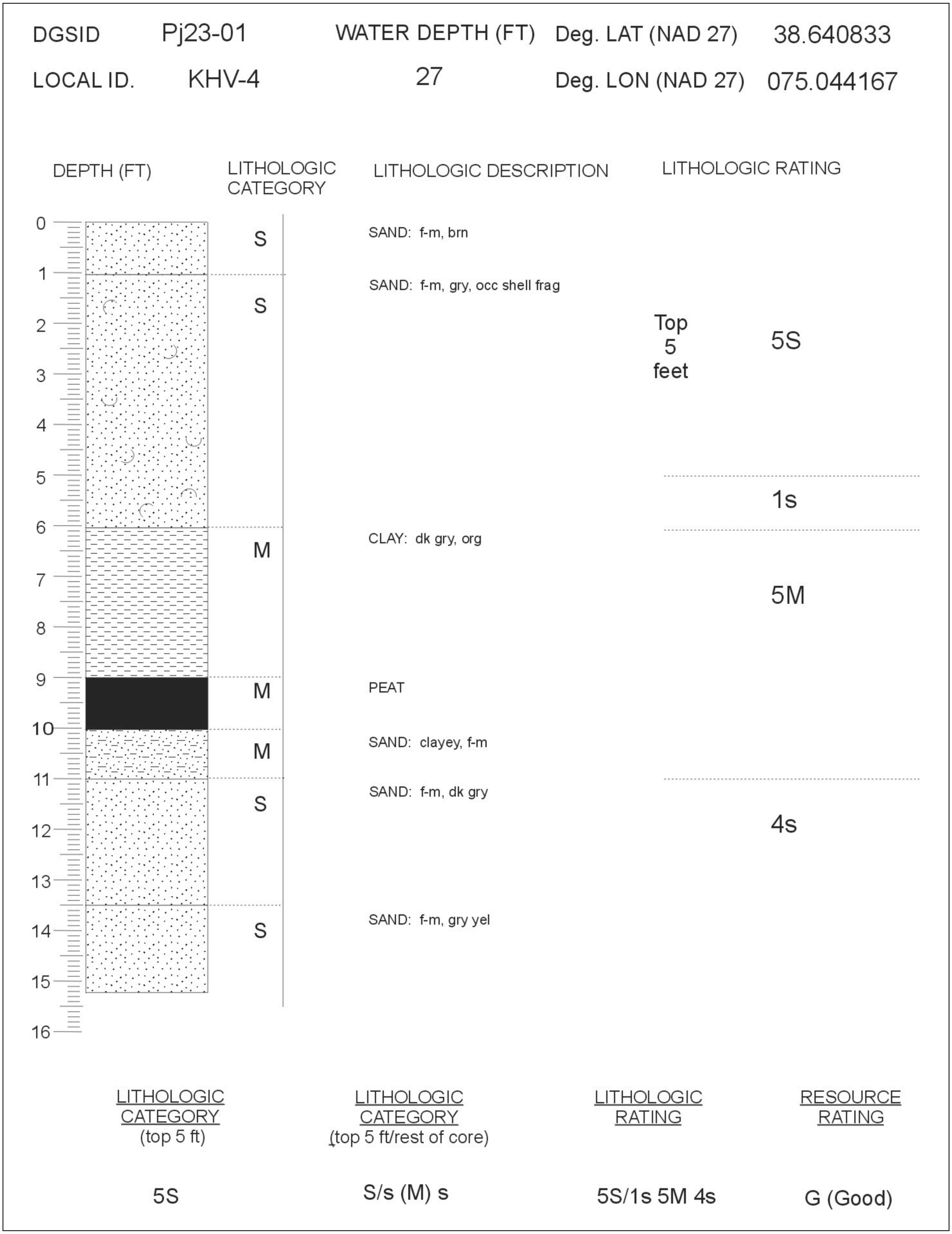

Figure 8. Core No. Pj23-01 as an example showing the lithologic and resource rating classification. A good (G) rating is assigned because the thickness of beach-quality sand at the seafloor is greater than five feet but less than ten feet. If the sand thickness was ten feet or greater, then the core would be rated as an excellent (E) sand resource.

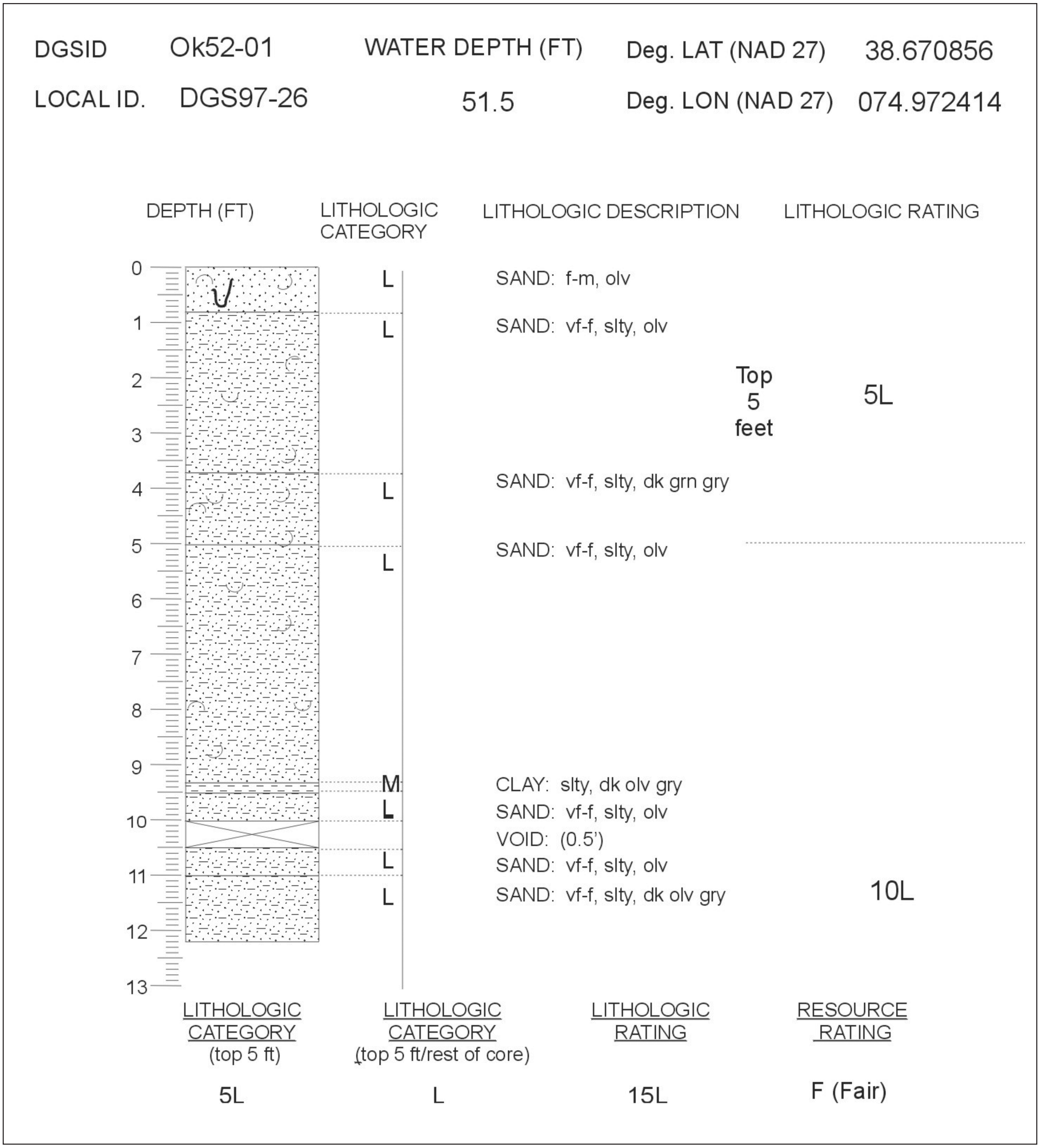

Figure 9. Lithologic description of Core No. Ok52-01 and an example of a fair (F)-rated core.

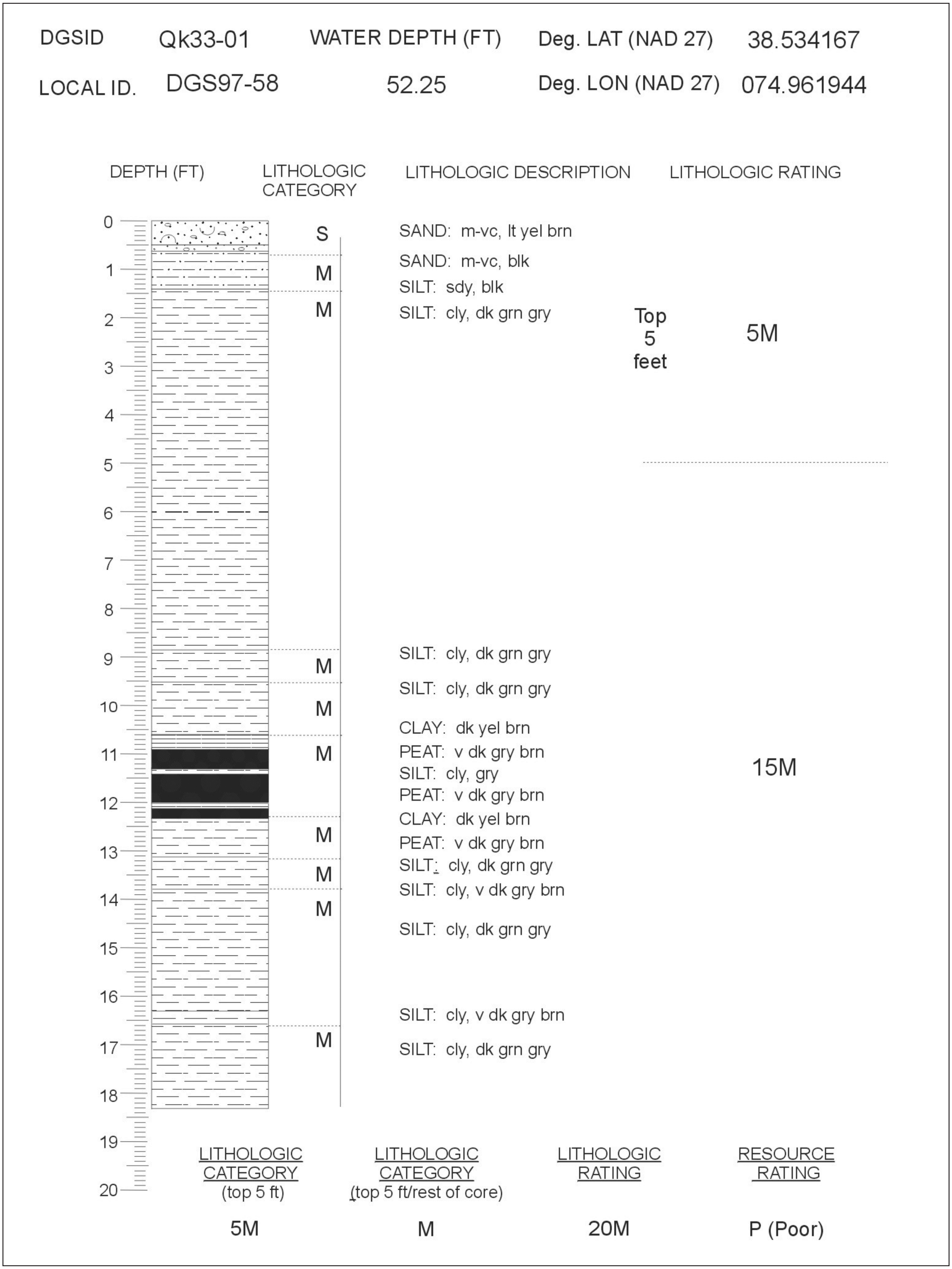

Figure 10. Lithologic description of Core No. Qk33-01 and an example of a poor (P)-rated core.

Table 4. Summary of RSA textural analyses for sand from DGS92 and DGS97 core samples. Data are averages of all samples from each core. Only sand samples were analyzed.

DGSID	Core Length (ft)	# Samples	Mean □	Sorting □	Skewness	Kurtosis	% Gravel	% Sand	% Mud
Oj23-02	16	13	2.38	0.46	-0.08	1.18	0.10	90.99	8.90
Pj45-01	18	14	1.47	0.69	0.11	1.14	14.25	81.18	4.56
Pk12-01	18	7	2.37	0.69	0.19	1.15	0.77	91.97	7.26
Pk51-01	20	9	1.58	0.58	0.07	0.70	5.50	86.26	8.24
Pl51-01	15	5	1.62	0.54	0.03	0.57	1.85	95.46	2.69
Pl55-01	2.5	1	1.62	0.67	0.20	1.62	10.52	84.72	4.76
Qj24-03	17	8	1.95	0.68	0.06	1.17	2.11	95.75	2.14
Qk13-01	20	11	1.45	0.59	0.14	0.68	7.44	84.14	8.42
Qk21-01	20	7	1.66	0.70	0.09	1.08	2.33	91.48	6.19
Qk43-01	11	2	1.86	0.59	-0.07	1.37	2.05	92.76	5.19
Rk11-01	19.5	2	2.37	0.52	-0.06	1.37	10.96	70.40	18.64
Rk21-01	16	4	2.33	0.72	0.10	1.01	3.04	92.60	4.36
Rk33-01	10.8	5	1.53	0.66	-0.18	1.09	0.63	97.77	1.59
Rl25-01	11.8	3	2.01	0.52	0.02	1.09	1.09	96.95	1.96
Rl31-01	16.2	7	1.65	0.58	-0.11	0.67	2.50	96.59	0.92
Ok42-01	5.46	6	2.07	0.36	0.17	1.09	0.60	96.64	2.76
Ok42-03	4.2	2	2.82	0.39	-0.57	1.60	0.44	80.00	19.56
Ok52-01	12.17	5	2.67	0.42	-0.32	1.79	0.22	96.08	3.69
Ok52-02	0.3	4	2.81	0.36	-0.22	1.59	0.08	93.48	6.44
Ok52-03	7.7	1	2.99	0.23	0.98	1.09	1.39	87.73	10.88
Ok52-04	5	3	2.90	0.24	0.07	1.22	0.05	94.45	5.50
Pk22-01	18.5	11	0.87	0.71	0.05	0.96	14.02	83.41	2.57
Pk32-01	9	6	1.44	0.63	0.02	1.15	8.09	89.99	1.92
Pk32-02	17.4	12	1.12	0.69	0.08	1.03	11.37	85.55	3.08
Pk42-01	7.42	5	1.42	0.66	-0.13	1.27	6.36	88.84	4.80
Pk42-02	18.5	9	1.31	0.59	-0.10	1.22	5.48	90.23	4.30
Pk52-01	7.8	5	1.11	0.70	0.01	1.02	7.18	88.29	4.53
Pk52-02	17.1	11	1.32	0.62	-0.01	1.12	7.63	85.64	6.72
Pk55-01	20	11	1.26	0.58	-0.02	1.07	4.31	93.20	2.48
Pl51-02	19.5	11	1.26	0.64	-0.01	0.98	4.97	90.66	4.37
Qk11-01	9.8	6	1.10	0.72	-0.02	1.03	13.97	81.45	4.58
Qk11-02	19	11	1.21	0.55	0.12	1.21	12.56	81.23	6.21
Qk12-01	8	4	1.46	0.74	0.08	0.90	6.61	84.02	9.37
Qk12-02	20	3	2.04	0.35	0.24	1.19	0.05	83.79	16.16
Qk12-03	14	6	1.72	0.55	0.02	1.15	5.22	85.90	8.88
Qk12-04	16	7	1.55	0.52	0.01	1.17	8.14	85.74	6.13
Qk12-05	6.42	3	1.12	0.73	0.05	0.93	6.86	85.92	7.22
Qk14-01	1.75	1	0.69	0.76	0.09	1.00	51.23	47.86	0.91
Qk14-02	19.5	9	0.97	0.65	0.03	1.09	14.06	81.62	4.33
Qk33-02	20	6	2.57	0.61	-0.16	1.13	0.25	62.26	37.49
Qk53-02	2.5	11	1.39	0.57	-0.12	1.04	2.30	96.79	0.91
Ql51-01	6.42	3	1.67	0.69	-0.06	0.84	0.33	96.41	3.26
Ql51-02	19.5	10	1.83	0.54	-0.08	1.44	6.90	81.34	11.76
Rk13-01	4.4	1	1.69	0.43	0.01	0.95	0.26	97.65	2.08
Rk13-03	19	8	1.33	0.66	-0.04	1.10	7.19	90.71	2.10
Rk13-04	20	12	1.38	0.62	-0.08	1.06	3.96	94.48	1.56
Rk23-01	2.42	1	2.03	0.46	-0.03	1.37	1.43	94.77	3.80
Rk23-02	3.42	1	2.01	0.43	-0.03	1.35	0.19	97.42	2.39
Rk23-03	4.75	2	1.92	0.45	-0.06	1.18	2.43	93.26	4.31
Rk23-04	19.9	11	1.28	0.71	-0.07	1.01	12.43	83.75	3.82
Rk23-05	18.9	10	2.14	0.53	-0.23	1.53	0.69	87.22	12.08
Rk25-01	17	13	1.76	0.36	-0.05	1.10	0.76	98.80	0.44
Rk34-02	18.5	11	1.10	0.65	-0.11	0.96	6.79	92.93	0.28
Rk35-01	1.5	1	2.02	0.29	0.02	0.95	0.00	99.54	0.46
Rk35-02	19.7	12	1.53	0.34	0.04	1.04	0.86	98.74	0.40
Rk35-03	20	12	2.14	0.35	-0.07	1.13	0.61	98.01	1.39
Rk35-04	20.2	11	1.72	0.53	-0.19	1.07	1.72	97.57	0.70
Rk35-05	3.1	1	1.47	0.40	-0.14	1.13	0.20	99.70	0.11
Rk44-01	2.08	1	1.33	0.33	-0.02	1.24	0.13	99.57	0.31
Rl11-01	19.4	8	2.18	0.39	0.05	1.06	0.56	92.21	7.23
Rl21-01	3.08	1	1.18	0.70	-0.06	0.93	1.68	97.98	0.34

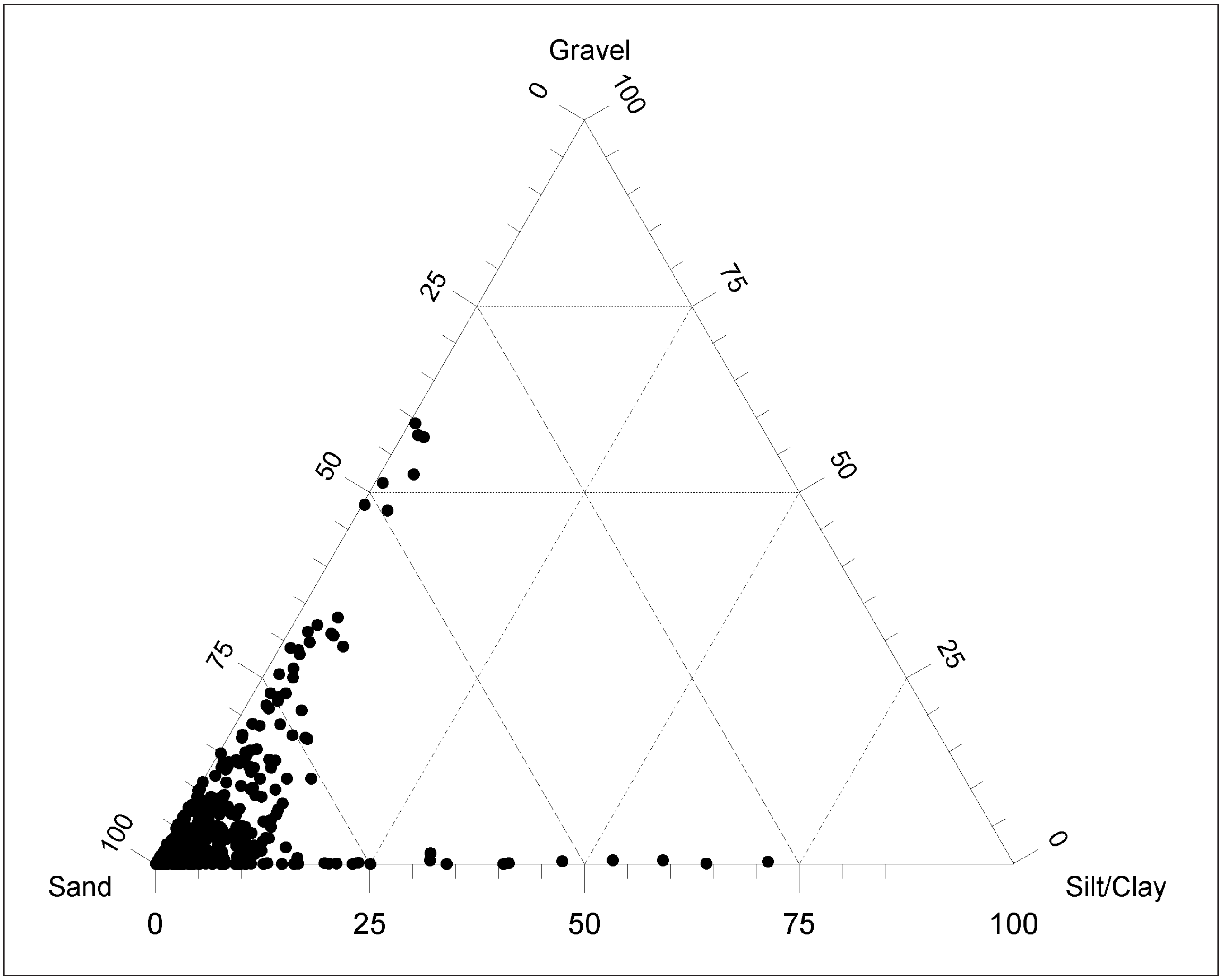

Figure 11. Triangular diagram of DGS92 and DGS97 textural data showing percentages of the gravel, sand, and mud (silt + clay) fractions.

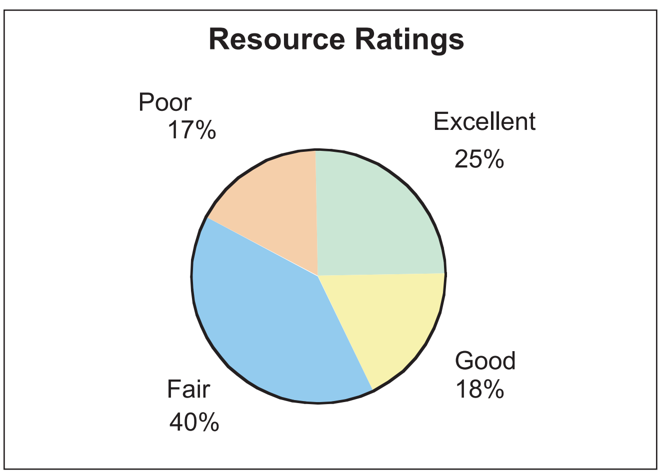

Figure 12. Resource rating percentages for the entire DGS offshore core database.

In federal waters, the excellent (E) deposits are found within the Outer Platform (Figure 3) that has a relatively planar, gentle-sloping bathymetry. Water depths range between 45 and 60 ft and there is a general slope to the east. These deposits cover 3.15 square miles. Assuming a thickness of 10 ft of sand, the area has approximately 32.5 million cubic yards (44 million tons) of potential sand resources.

The other area of sand resources defined in federal waters is in the vicinity of Fenwick Shoal (Plate 1). Fenwick is the largest and northernmost of the shoals found lying on the Outer Platform. The best resources are on the shoal itself and directly to the west of the shoal. Potential resources for Fenwick Shoal in an area of about 1.1 square miles are about 11.1 million cubic yards (15 million tons). In total, approximately 43.6 million cubic yards (59 million tons) of beach-quality sand may be found in federal waters.

Resources in State Waters and Borrow Locations

Within state waters, twelve groupings with potential excellent (E) and good (G) sand resources lie within the Attached Shoal Field and Shoreface, Inner Platform, and Detached Shoal Field geomorphic regions (Plate 1). Combined, the area covers 6.7 square miles and contains over 61.5 million cubic yards (83 million tons) of beach-quality sand.

The good (G)-rated deposits of the Attached Shoal Field and Shoreface are composed of beach-quality sand but in thickness much less than their offshore counterparts (five to ten feet thick). This may indicate that the sand deposits are reworked Holocene deposits influenced by modern littoral processes. Farther offshore (but still within state waters) excellent (E)-rated deposits are found in the Inner Platform and Detached Shoal Field and again are probably related to former inlet and strandplain depositional systems.

Figure 13 shows proposed U.S. Army Corps of Engineers (USACE) borrow sites for the Rehoboth Beach/Dewey Beach, Bethany/South Bethany, and Fenwick Island beach fills. The proposed borrow sites are estimated to contain nearly 80 million cubic yards of sand (U.S. Army Corps of Engineers, 1996, 1997, 2000). Some of the resources within USACE borrow areas though, are limited because the borrow sites are located within former military firing ranges or may have biological limitations. Consequently, there may be a need to look farther offshore or northward for beach-quality sand.

Figure 13 also shows the locations of the two DNREC Fish and Wildlife artificial reef sites within the study area. No vibracores were taken in or near the existing artificial reef sites; however, the DNREC Division of Fish and Wildlife has noted sand and hard sand substrates in those areas (DNREC, unpublished data, 1999). Neither of the artificial reef sites in the study area are located within the USACE borrow areas.

Potential Offshore Aggregate Resources

One of the characteristics of the sands in the area off Indian River Inlet is that they commonly contain a visible percentage of gravel. Of the 268 cores in the offshore database, 73 contain visible gravel. However, only core Rj24-02 (KHV-48) contains a significant gravel component (50 percent G and greater than 2 ft thick) within five feet of the seafloor. A significant gravel component is also described for core Pk22-01 (DGS97-59), although the gravel layer lies below a few feet of sand (Appendix B). These cores did not contain any M (mud) or L (fine or silty sand) lithologic categories. No distinct groupings of aggregate resources have emerged from this study, therefore potential volumes of aggregates have not been calculated. The area within the brown circles on Plate 1 may hold potential for small aggregate resources;

Thirteen cores contain gravel percentages ranging from 10 to 50 percent by weight for individual samples and assigned a gS lithologic rating (Appendix B). These cores did not contain any M or L in them. Because past replenishment projects included gravelly material in the beach fill, the sediment in these cores was determined to be more appropriate for future beach replenishment projects than for aggregate.

Summary Statistics

Although the DGS97 vibracore locations were chosen to find beach-quality sand, the 1997 dataset shows that 51 percent of the cores were considered excellent (E) or good (G) sources of sand. The remaining cores (49 percent) in the 1997 dataset contained sediment generally considered to be too fine for beach replenishment. Because of the inherent bias in sampling, no statistical tests were conducted on the samples taken from the vibracores. More vibracores from areas not yet evaluated may be helpful in determining which statistical tests should be conducted.

DISCUSSION

Influence of Paleovalley Channels and Geomorphic Regions

Williams (1999) developed a framework for characterizing five depositional units as potential beach replenishment sources. He found that the offshore stratigraphy consists of filled paleovalleys that contribute to varied textures within the depositional units. As a result, adjacent vibracores may have different textural properties because the former fluvial systems cross-cut older depositional units. This study delineates sand and aggregate resources based on individual core lithologies and not by the depositional units described by Williams (1999) in Table 2.

Figure 6 shows the general locations of paleovalley channels as interpreted by Williams (1999) using seismic data collected in 1992 and 1993. The paleovalley channels have little or no surface expression on the sea floor, and they range in depths below the seafloor surface between 45 ft and 80 ft. Williams (1999) described two generations of erosion and subsequent infilling of the channels with some channels containing mostly mud and others sand. This study has found no influence of the paleovalley channels on the sediment quality or resource rating of cores because most of the cores were less than 20 ft in length and the sediments filling the paleovalleys occur too deep to influence this resource evaluation.

Of the 32 cores located within the paleovalley channel boundaries and assigned excellent (E) or good (G) resource ratings, all but one core are assumed to be filled with reworked (Holocene) sediments. Log descriptions from cores Pj12-04 (JCK E3 81) and Pk55-01 (DGS97-46) were noted to have a distinct contact assumed to be the Holocene/Pleistocene contact at about seven to ten feet below the seafloor surface (at water depths of 37 ft for Pj12-04 and 67.5 ft for Pk55-01). Charred wood located just above the described Holocene/Pleistocene contact was sampled from Pj12-04 and yielded a radiocarbon date of 6220 +/- 90 years (Ramsey and Baxter, 1996). Core Pk55-01 was not sampled to confirm the Holocene/Pleistocene contact. Wood extracted from core Ql51-02 (DGS97-38) ten feet below the seafloor surface was given a radiocarbon date of 47,110 ybp +/- 1600 years (www.udel.edu/dgs/radcarbtab.pdf) and may indicate a thinning of the Holocene sand sheet within the outer platform.

The quality of sediment more closely corresponds to geomorphic region than to proximity to paleovalley channels or to bathymetry. Figure 14 shows the percentages of resource ratings of cores for each geomorphic region. Many of the cores with resource ratings of excellent (E) and good (G) are found within the Inner and Outer Platforms and generally near the Indian River Inlet or to the south. Plate 1 shows several cores grouped together by resource rating. Most excellent and good groupings are found within state waters and are assumed to be tidal deposits of a former Indian River Inlet during periods of lower sea level (cores

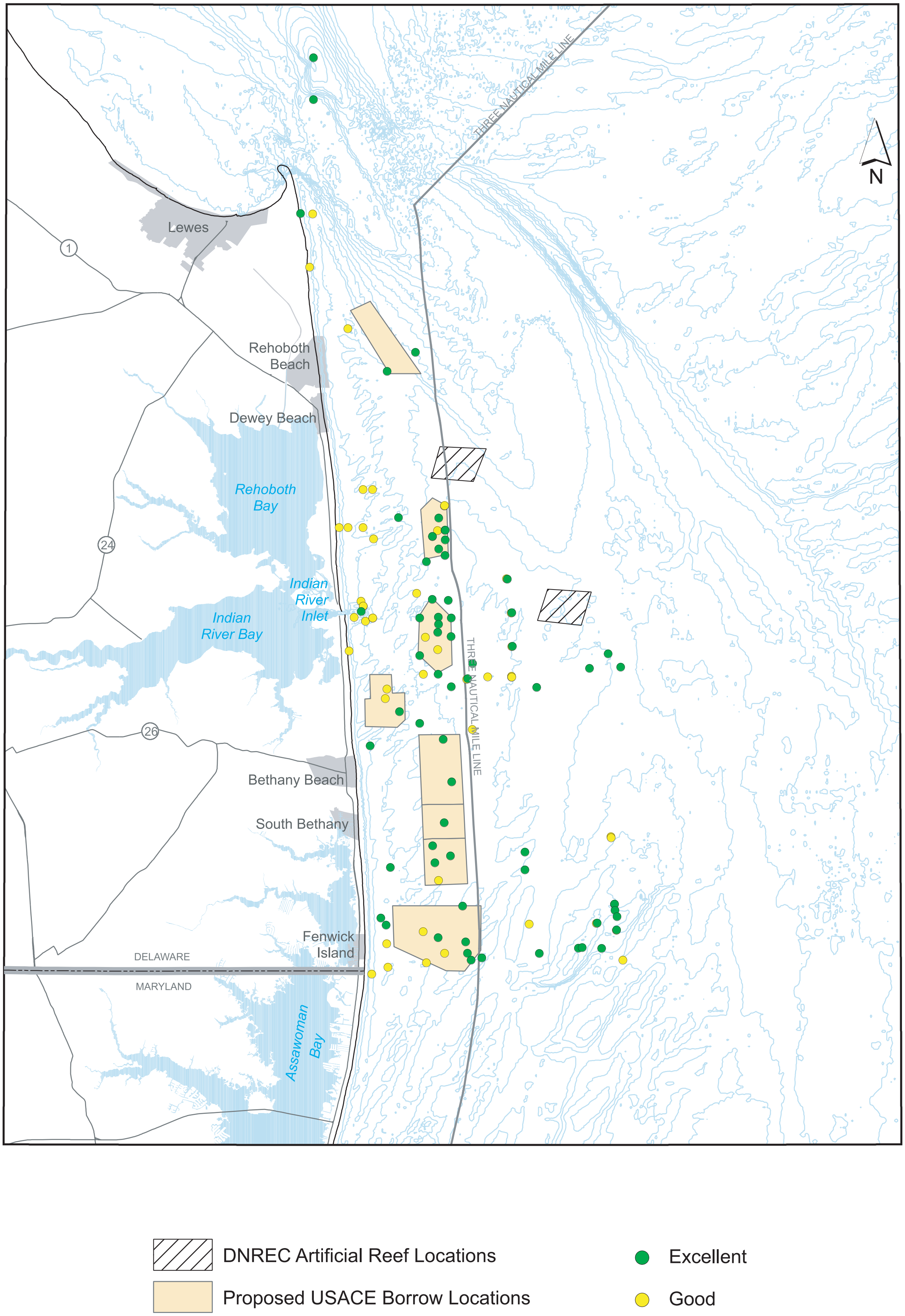

Figure 13. USACE proposed borrow sites, DNREC artificial reef locations, and locations of excellent and good cores.

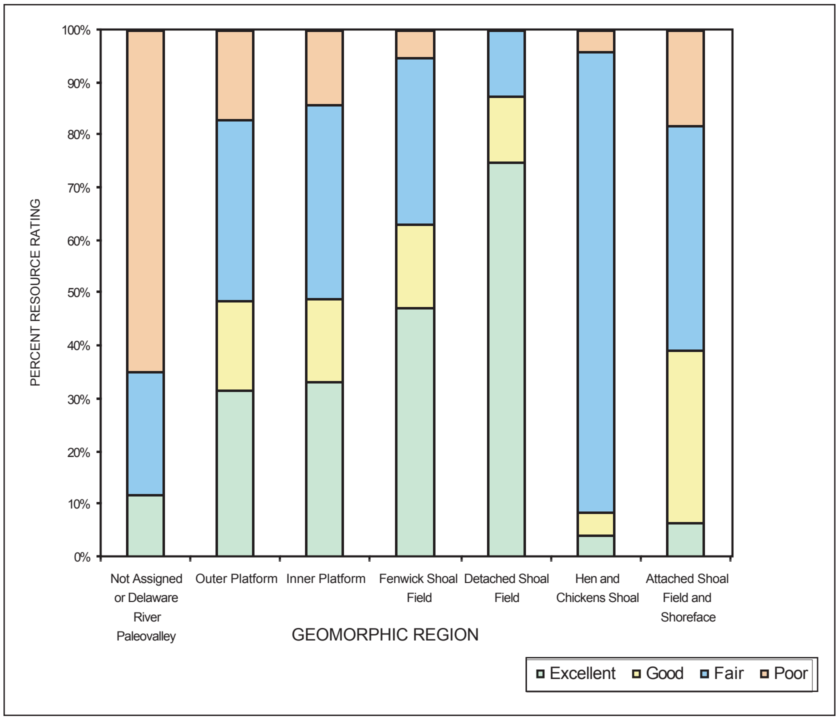

Figure 14. Resource ratings of cores for each geomorphic region.

Pj45-03 to Qj15-02) and extend into federal waters (cores Pk32-02 to Qk13-01). To the south, the Detached Shoal Field and Fenwick Shoal Field contain a significant amount of excellent (E) and good (G) resource ratings as would be expected from shoal formations.

The depth of water from which the cores were taken has no correlation with the resource rating quality (Figure 15), although most poor (P) cores are located in waters greater than 90 feet. In general, the offshore region of Delaware is too complex to rely on the depth of water to determine the quality of the sediment below.

Relationships to Geology

Williams (1999) described the DGS92 vibracores in units that relate to the offshore geology (Table 2). In general, cores containing Williams' (1999) depositional Units A, C, D, and E (the cores with the combination of Holocene-age sediments and Pleistocene Omar and Beaverdam sediments) were placed in the excellent (E) resource rating. Cores containing the combinations of Units A and D, A and B, and B and C (Holocene nearshore and Pleistocene lagoonal deposits) did not contain beach-quality sand and were generally placed in the fair (F) or poor (P) categories.

SUMMARY

The Delaware inner continental shelf stratigraphy varies from subparallel depositional units to areas with no consistent geometry due in part to paleodrainage patterns of former glacial periods (Williams, 1999). The complex and cross-cutting relationships of the offshore geological units make predicting locations of beach-quality sand a difficult task. The "stack-unit mapping" method allows us to evaluate the contents of each vibracore in the DGS Core and Sample Repository and quantify the thicknesses of gravel, sand, silt, and mud. The results of the method were combined with a geographic information system to produce maps that show us where to expect beach-quality sand and allow us to estimate the aerial extent and volume of sand resources in the Atlantic offshore Delaware. Maps produced from the "stack-unit mapping" method can be used for delineating potential borrow areas and can help in the design of future vibracore sampling projects.

The criteria for finding excellent and good sand resources are based on grain size, thickness, and proximity to the seafloor surface. Sixteen areas offshore Delaware are identified as excellent or good sand resource areas covering nearly 11 square miles and volume estimates of nearly 105 million cubic yards (142 million tons). Most of the areas with beach-quality sand can be found offshore Indian River Inlet in both state and federal waters. Additional sand resources are available in the Detached and Fenwick Shoal Fields.

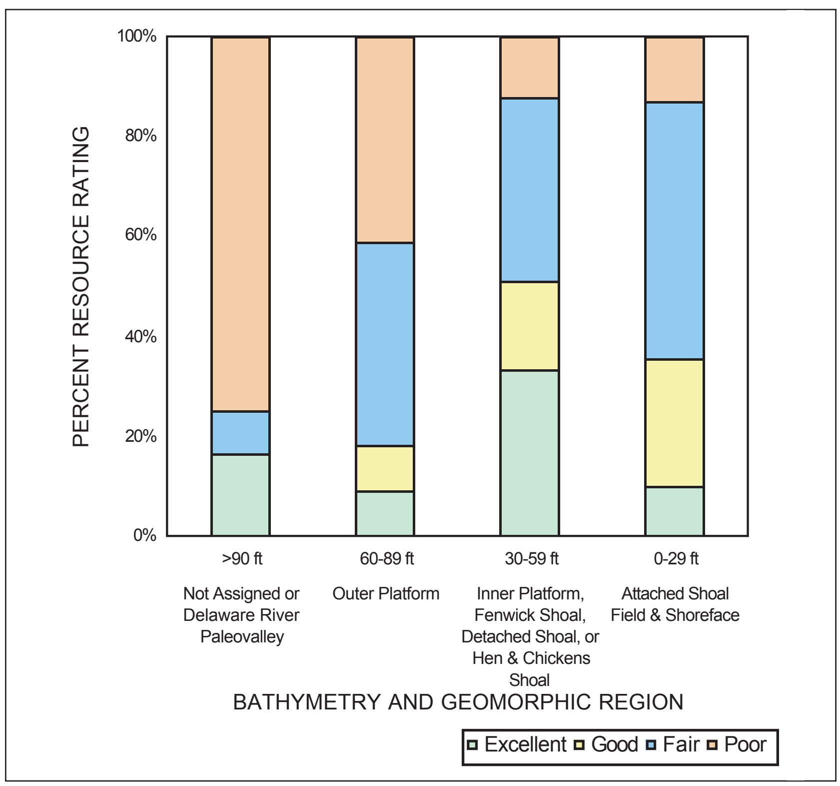

Figure 15. Comparison of resource ratings of cores to bathymetry and geomorphic region.

Gravel is only found sporadically throughout the study area, in part due to sampling methods, and no significant aggregate resources were found. Gravelly sand (gS) is common (especially offshore Indian River Inlet) and may be appropriate for future beach replenishment projects because the percentage of gravel in a sand matrix is usually below 50 percent.

REFERENCES CITED

Andres, A. S., 1986, Geohydrology of the northern coastal area, Delaware – Sheet 1, Basic geohydrologic data: Delaware Geological Survey Hydrologic Map Series No. 5.

Andres, A. S., 1991, Methodology for mapping ground-water recharge areas in Delaware's coastal plain: Delaware Geological Survey Open File Report No. 34, 18 p.

Belknap, D. F., and Kraft, J. C., 1977, Holocene relative sea-level changes and coastal stratigraphic units on the northwest flank of the Baltimore Canyon trough geosyncline: Journal of Sedimentary Petrology, v. 47, no.2, p. 610-629.

Belknap, D. F., and Kraft, J. C., 1981, Preservation potential of transgressive coastal lithosomes on the U. S. Atlantic shelf: Marine Geology, v. 42, p. 429-442.

Belknap, D. F., and Kraft, J. C., 1985, Influence of antecedent geology on stratigraphic preservation potential and evolution of Delaware's barrier systems: Marine Geology, v. 63, p.235-262.

Benson, R. N., ed., 1990, with contributions by A. S. Andres, R. N. Benson, K. W. Ramsey, and J. H. Talley, Geologic and hydrologic studies of Oligocene- Pleistocene section near Lewes, Delaware: Delaware Geological Survey Report of Investigations No. 48, 34 p.

Benson, R. N., Andres, A. S, Roberts, J. H., and Woodruff, K. D., 1986, Seismic stratigraphy along three multichannel seismic reflection profiles off Delaware's coast: Delaware Geological Survey, Newark, Delaware, Miscellaneous Map Series No. 4.

Berg, R. C., Kempton, J. P. and Cartwright, K., 1984, Potential for contamination of shallow aquifers in Illinois: Illinois Geological Survey Circular 532, 30 p. with maps.

Chrzastowski, M. J., 1986, Stratigraphy and geologic history of a Holocene lagoon system: Rehoboth Bay and Indian River Bay, Delaware: Newark, Delaware, University of Delaware, unpublished Ph.D. dissertation, 444 p.

Collins, D. J., 1982, Morphology, hydrodynamics, and subsurface stratigraphy of an ebb- tidal delta: Indian River Inlet, Delaware: Newark, Delaware, University of Delaware, unpublished M. S. thesis, 222 p.

Duane, D. B., Field, M. E., Meisburger, E. P., Swift, D. J. P., and Williams, S. J., 1972, Linear shoals on the Atlantic inner continental shelf, Florida to Long Island, *in* Swift, D. J. P., Duane, D. B., and Pilkey, O. H., eds., Shelf sediment transport: Process and pattern: Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, Inc., p. 447-498.

Duffield Associates, 1999, Geotechnical Investigation: 1999 Vibrocoring along the Delaware Coast, Dewey/Rehoboth PED: Draft Report, DAI W.O. 3769.GI, USACE Contract No. DACW-61-98-D-0008, Task Order 8, Modification 1, Wilmington, Delaware, 5 p. plus appendixes.

___2000, Geotechnical Investigation: 2000 Vibrocoring in the Atlantic Ocean, Bethany/South Bethany PED, Delaware: Contract Report, DAI W.O. 3769.GY.01 USACE Contract No. DACW-61-98-D-0008, Task Order 22, Wilmington, Delaware, 6 p. plus appendixes.

Eitner, V., 1996, The effect of sedimentary texture on beach fill longevity, Journal of Coastal Research v.12, p. 447-461.

Faucett Associates, Inc., 1998, The economic effects of a five year nourishment program for the ocean beaches of Delaware: Final Report to the Delaware Department of Natural Resources and Environmental Control, Work Order No. 873726, 40 p. plus appendixes.

Field, M. E., 1976, Quarternary evolution and sedimentary record of a Coastal Plain shelf: Central Delmarva Peninsula, Mid-Atlantic Bight, U.S.A., The George Washington University, Washington D.C., unpublished Ph.D. dissertation, 200 p. plus appendixes.

___1979, Sediments, shallow subbottom structure, and sand resources of the inner continental shelf, central Delmarva peninsula: United States Army Corps of Engineers Technical Paper, No. 79-2, Fort Belvoir, Virginia, Coastal Engineering Research Center, 122 p.

Field, M. E., Meisburger, E. P., Stanley, E. A., and Williams, S. J., 1979, Upper Quaternary peat deposits on the Atlantic inner shelf of the United States: Geological Society of America Bulletin, Part 1, v. 90, p. 618-628.

Fletcher, C. H., 1986, Stratigraphy and reconstruction of the Holocene transgression: A computer aided study of the Delaware Bay and inner Atlantic Shelf, Newark, Delaware, University of Delaware, unpublished Ph.D. dissertation, 468p.

Groot, J. J. and Jordan, R. R., 1999, The Pliocene and Quaternary deposits of Delaware: palynology, ages, and paleoenvironments: Delaware Geological Survey Report of Investigations No. 58, 41 p.

Groot, J. J., Ramsey, K. W., and Wehmiller, J. F., 1990, Ages of the Bethany, Beaverdam, and Omar formations of southern Delaware: Delaware Geological Survey Report of Investigations No. 47, 19 p.

John, C. J., 1977, Internal sedimentary structures, vertical stratigraphic sequences, and grain-size parameter variations in a transgressive coastal barrier complex: the Atlantic coast of Delaware: University of Delaware Sea Grant Publication, No. DEL-SG-10-77, 287 p.

Kempton, J. P., 1981, Three-dimensional geologic mapping for environmental studies in Illinois: Illinois Geological Survey Environmental Geology Note 100, 43 p.

Kempton, J. P. and Cartwright, K., 1984, Three-dimensional geologic mapping: a basis for hydrogeologic and land-use evaluations: Association of Engineering Geologists Bulletin, v. 21, no. 3, p. 317-335.

Komar, P. D., 1998, Beach Processes and Sedimentation, 2nd edition, Prentice Hall, NJ, 544 p.

Kraft, J. C., 1971, Sedimentary facies patterns and geologic history of a Holocene marine transgression: Geological Society of America Bulletin, v. 82, p. 2131-2158.

Kraft, J. C. and John, C. J., 1976, The geological structure of the shorelines of Delaware: University of Delaware Sea Grant Publication No. DEL-SG-14-76, 106 p.

___1979, Lateral and vertical facies relations of transgressive barrier: The American Association of Petroleum Geologists Bulletin v. 63, p. 2145-2163.

Kraft, J. C., Chrzastowski, M. J., Belknap, D. F., Toscano, M. A., and Fletcher, C. H., 1987, The transgressive barrier-lagoon coast of Delaware: Morphostratigraphy, sedimentary sequences and responses to relative rise in sea level, *in* Nummedal, D., Pilkey, O. H., and Howard, J. D., eds., Sea-level fluctuation and coastal evolution, Society of Economic Petrologists and Paleontologists Special Publication No. 41, p. 129-143.

Maryland Geological Survey, 1998, Metadata for the Chesapeake Bay Earth Science Study (CBESS): physical properties of surficial sediments, Chesapeake Bay, Maryland, website http://mgs.dnr.md.gov.

McBride, R. A. and Moslow, T. F., 1991, Origin, evolution, and distribution of shoreface sand ridges, Atlantic inner shelf, U. S. A.: Marine Geology, v. 97, p. 57-85.

McGee, R. G., 1995, Geoacoustic study of Delaware Atlantic Coast from Cape Henlopen to Fenwick Island: United States Army Corps of Engineers, Waterways Experiment Station Technical Report HL-95-15, 84 p. plus appendixes.

McKenna, K. K., 2000, Using the "Stack-Unit Mapping" method for evaluating Delaware's offshore sand sources, Hen and Chickens Shoal: Abstracts from the 2000 Assateague Shore and Shelf Workshop, Conway, South Carolina.

Moody, D. W., 1964, Coastal morphology and processes in relation to the development of submarine sand ridges off Bethany Beach, Delaware: Baltimore, Maryland, Johns Hopkins University, unpublished Ph.D. dissertation, 167 p.

Oostdam, B. L., 1971, Suspended sediment transport in Delaware Bay: Newark, Delaware, University of Delaware, unpublished Ph.D. dissertation, 316 p.

Ramsey, K. W., 1997, Geology of the Milford and Mispillion River Quadrangles: Delaware Geological Survey Report of Investigations No. 55, 40 p.

___1999a, Beach sand textures from the Atlantic coast of Delaware: Delaware Geological Survey Open File Report No. 41, 6 p.

___1999b, Cross section of Pliocene and Quaternary deposits along the Atlantic coast of Delaware: Delaware Geological Survey Miscellaneous Map No. 6.

Ramsey, K. W. and Baxter S. J., 1996, Radiocarbon dates from Delaware: A compilation: Delaware Geological Survey, Report of Investigations No. 54, 18 p.

Ramsey, K. W. and McKenna, K. K., 1999, Geologic framework, distribution, and quality of sand resources in the Atlantic offshore Delaware: Delaware Geological Survey Contract Report to the Minerals Management Service, Contract No. 14-35-0-001-30760, 19 p. plus appendixes.

Ramsey, K. W., Schenck, W. S., and Wang, L. T., 2000, Physiographic regions of the Delaware Atlantic Coast: Delaware Geological Survey Special Publication No. 25, 1 sheet, scale 1:60,000.

Rine, J. M., Covington, E., Shafer, J. M., and Berg, R. C., 1999, The use of stack-unit mapping to predict pathways of contaminants through Tertiary-age strata; A/M areas, Savannah River Site, SC: Abstracts with Programs, Geological Society of America, v.31, p. 79.

Sheridan, R. E., Dill, C. E., and Kraft, J. C., 1974a, Holocene sedimentary environment of the Atlantic inner shelf off Delaware: Geological Society of America Bulletin, v. 85, p. 1319-1328.

___1974b, Holocene sedimentary environment of the Atlantic inner shelf off Delaware: College of Marine Studies, University of Delaware, Technical Report No. 31, 12 p. plus appendixes.

Swift, D. J. P., Kofoed, J. W., Saulsbury, F. P., and Sears, P., 1972, Holocene evolution of the shelf surface, central and southern Atlantic shelf of North America, *in* Swift, D. J. P., Duane, D. B., and Pilkey, O. H., eds., Shelf sediment transport: Process and pattern: Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, Inc., p. 499-574.

Swift, D. J. P., 1973, Delaware shelf valley: Estuary retreat path, not drowned river valley: Geological Society of America Bulletin, v. 84, p. 2743-2748.

Talley, J. H., and Windish, D. C., 1984, Instructions for preparation of DGS database schedules: Delaware Geological Survey Special Publication No. 11, 119 p.

Terchunian, A. V., 1985, Hen and Chickens Shoal, Delaware: Evolution of a modern nearshore marine feature: Newark, Delaware, University of Delaware, unpublished M. S. thesis, 148 p.

Toscano, M. A., Kerhin, R. T., York, L. L., Cronin, T. M., and Williams, S. J., 1989, Quaternary stratigraphy of the inner continental shelf of Maryland: Maryland Geological Survey, Report of Investigations No. 50, 116 p.

Twichell, D. C., Knebel, H. J., and Folger, D. W., 1977, Delaware River, evidence of its former extension to Wilmington Submarine Canyon: Science, v. 195, p. 483-484.

Underwood, S. G., and Anders, F. J., 1987, Analysis of vibracores from shoals east of Fenwick Island, Delaware: United States Army Corps of Engineers, Coastal Engineering Research Center, Waterways Experiment Station, Draft Final Report, 22 p. plus appendixes.

U.S. Army Corps of Engineers, 1966, Beach erosion control and hurricane protection along the Delaware coast: Office of the District Engineer, Philadelphia.

U.S. Army Corps of Engineers, 1975, Beach erosion control and hurricane protection, Delaware coast: General Design Memorandum, Phase 2: Office of the District Engineer, Philadelphia.

U.S. Army Corps of Engineers, 1976, Beach erosion control and hurricane protection, Delaware coast: General Design Memorandum, Phase 2, Supplement No. 1: Office of the District Engineer, Philadelphia.

U.S. Army Corps of Engineers, 1996, Delaware Coast from Cape Henlopen to Fenwick Island, Rehoboth Beach/Dewey Beach Interim Feasibility Study: U.S. Army Engineer District, Philadelphia, 144 p. plus appendixes.

U.S. Army Corps of Engineers, 1997, Delaware Coast from Cape Henlopen to Fenwick Island, Bethany Beach/South Bethany Interim Feasibility Study, Draft Feasibility Report and Draft Environmental Impact Statement: U.S. Army Engineer District, Philadelphia, 109 p.

U.S. Army Corps of Engineers, 1998, Delaware Coast from Cape Henlopen to Fenwick Island, Bethany Beach/South Bethany Interim Feasibility Study, Final Feasibility Report and Environmental Impact Statement: U.S. Army Engineer District, Philadelphia, 51 p. plus appendixes.

U.S. Army Corps of Engineers, 2000, Delaware Coast from Cape Henlopen to Fenwick Island, Fenwick Island Interim Feasibility Study, Draft Integrated Feasibility Report and Environmental Impact Statement: U.S. Army Engineer District, Philadelphia, 202 p. plus appendixes.

Weil, C. D., 1976, A model for the distribution, dynamics, and evolution of Holocene sediments and morphologic features of Delaware Bay: Newark, Delaware, University of Delaware, unpublished Ph.D. dissertation, 408 p.

Williams, C. P., 1999, Late Pleistocene and Holocene stratigraphy of the Delaware inner continental shelf: Newark, Delaware, University of Delaware, unpublished M.S. thesis, 175 p.

Woodward-Clyde Federal Services, 1997, Results of vibrocore program; offshore Fenwick Island, Delaware, Draft Report, Contract No. DACW61-95-D-005: Wayne, New Jersey, 5 p. plus appendixes.

Appendix A

Delaware Geological Survey (DGS) Offshore Core Inventory and Reference List

ASB – Assawoman Bay Quadrangle
BEB – Bethany Beach Quadrangle
CAH – Cape Henlopen Quadrangle
FHN – Fish Haven Quadrangle
FWS – Fenwick Shoal Quadrangle
NOM – North Middle Quadrangle
NOR – North Quadrangle
OFS – Overfall Shoal Quadrangle
OCL – Old Channel Quadrangle
REB – Rehoboth Beach Quadrangle
SOM – South Middle Quadrangle
SOU – South Quadrangle

REFERENCE NUMBER	AUTHOR	CORE NUMBER
1	Delaware State Highway Dept., unpublished data cores	B6, B7, B8, B9
2	Oostdam, B.L., 1971.	cores 70046, 70047,70049, 70050, 70053, 70055, 70059, 70061, 70100, 70117, 70129, 70132
3	Sheridan, R.E., C.E. Dill, J.C. Kraft, 1974a.	SDK cores (1-16)
4	Sheridan, R.E., C.E. Dill, J.C. Kraft, 1974b.	SDK cores (1-16)
5	U.S. Army Corps of Engineers, 1975.	SDK cores (1-16)
6	U.S. Army Corps of Engineers, 1976.	KHV cores (1-11)
7	Field, M.E., 1976.	Core13
8	Weil, C.D., 1976.	W176, W1776, W2970, W3076, W3176, W5376, W5576, W5776,
9	Field, M.E., 1979.	cores 1,2,6,7,8,9,10,12 (incl.site map, no core descriptions provided)
10	Collins, D.J., 1982.	JCKIRI181 through JCKIRI481
11	Army Corps of Engineers, unpublished data	KHV cores (12-30)
12	Belknap, D.F., and Kraft, J.C., 1985.	JCK__81 cores (A1-A3, B1-B3, C1-C3, D1-D3, E1-E3, F1-F3, G1-G3, H1, H3, I1-I3, J1-J3, K1-K3, L1-L3)
13	Terchunian, A.V., 1985.	JCK HCS 1 & JCK HCS 2
14	Fletcher, C.H., 1986.	referenced JCK__81 cores, SDK cores (1-16)
15	Underwood, S.G., and Anders, F.J., 1987.	cores 3-1, 3-2, 3-4, 3-11, 8-3, 8-6
16	Delaware Geological Survey, unpublished data	cores 70121, 70129, 70135, DGS92- cores (1-15A), DGS97- cores (2-60.2)
17	McGee, R.G., 1995.	KHV cores (44-51)
18	U.S. Army Corps of Engineers, 1996.	KHV cores (31-58)
19	Woodward-Clyde Federal Services, 1997.	KHV cores (59-80)
20	Duffield Associates, Inc., 1999.	KHV cores (81-92R2)
21	Duffield Associates, Inc., 2000.	KHV cores (93-115) DRV cores (68R1- 73R2)

Reference numbers (final column of database), author(s), and year of publication from which vibracore data are cited. Complete references are given in the references cited section of this publication.

Appendix A (cont.)

DGS ID	Local ID	Quad	Water Depth(ft)	Total Length of Core (ft)	Deg. LAT (NAD 27)	Deg. LON (NAD 27)	Reference Number
Mj32-01	W3176	CAH	40	5.9	38.8717	075.062	8
Mj41-01	W3070	CAH	140	11.5	38.8517	075.078	8
Mj41-02	70100	CAH	140	0.5	38.8500	075.077	2
Mj41-03	70047	CAH	140	0.75	38.8522	075.0817	2
Mj41-04	70046	CAH	142	0.6	38.8522	075.0814	2
Mj45-01	70051 70052	CAH	30	0.5	38.8500	075.0050	2
Mj51-01	W1776	CAH	90	15.75	38.8333	075.0783	8
Mk31-01	70053	CAH	32	0.25	38.8715	074.9823	2
Ni35-12	JCK A1 81	CAH	17	14.1	38.7833	075.0856	12, 14
Ni35-13	JCK A2 81	CAH	21	20.3	38.7833	075.0833	12, 14
Nj23-01	70049	CAH	101	0.5	38.8100	075.0497	2
Nj23-02	70050	CAH	101	0.8	38.8100	075.0497	2
Nj23-03	70117	CAH	98	3.5	38.8100	075.0478	2
Nj31-01	JCK A3 81	CAH	32	29.5	38.7833	075.0783	12, 14
Nj33-01	70059	CAH	87	0.5	38.7933	075.0367	2
Nj33-03	70129	CAH	97	0.33	38.7933	075.0367	2
Nj51-03	JCK B1 81	CAH	10	32.8	38.7600	075.0800	12, 14
Nj51-04	JCK B2 81	CAH	19	26.2	38.7600	075.0750	12, 14
Nj51-05	JCK B3 81	CAH	30	27.6	38.7600	075.0667	12, 14
Nj52-01	KHV-11	CAH	16	16	38.7531	075.0561	6
Nj52-02	JCK HCS 1	CAH	12	5.9	38.7617	075.0597	13
Nj52-03	JCK HCS 2	CAH	13	14.1	38.7625	075.0617	13
Nj54-01	SDK 11	CAH	76	28.7	38.7515	075.0208	3, 4, 14
Nk32-01	70132	OFS	113	1.1	38.7867	074.9733	2
Nk32-02	70061	OFS	110	1.25	38.7867	074.9733	2
Nk33-01	SDK 4	OFS	110	29	38.7833	074.9639	3, 4, 14
Nk41-01	70063	OFS	74	0.3	38.7700	074.9933	2
Nk41-02	SDK 12	OFS	73	27.5	38.7694	074.9958	3, 4, 14
Nk42-01	SDK 5	OFS	50	29.5	38.7750	074.9736	3, 4, 14
Oj12-01	KHV-81	REB	27.6	15.2	38.7399	075.0541	20
Oj13-01	KHV-10	REB	27	20	38.7361	075.0456	6
Oj13-02	KHV-35	REB	24.3	20	38.7381	075.0472	18
Oj13-03	KHV-82R1	REB	29	4.6	38.7406	075.0472	20
Oj13-04	KHV-82R2	REB	26.2	16.5	38.7407	075.0473	20
Oj13-05	KHV-83	REB	30.3	15.8	38.7336	075.0489	20
Oj13-06	KHV-84	REB	32.6	17	38.7368	075.0426	20
Oj21-09	JCK C1 81	REB	18	32.8	38.7167	075.0750	12, 14
Oj21-10	JCK C2 81	REB	29	30	38.7167	075.0667	12, 14
Oj22-01	SDK 6	REB	38	13.6	38.7181	075.0556	3, 4, 14
Oj22-02	JCK C3 81	REB	36	26.2	38.7167	075.0600	12, 14
Oj23-01	KHV-9	REB	27	16	38.7289	075.0472	6
Oj23-02	DGS92-1	REB	33.5	16	38.7175	075.0333	16
Oj23-03	KHV-58	REB	39.7	20	38.7331	075.0586	18
Oj23-04	KHV-85	REB	32.2	20	38.7313	075.0408	20
Oj23-05	KHV-86	REB	33.4	17.8	38.7273	075.0439	20

Appendix A (cont.)

DGS ID	Local ID	Quad	Water Depth(ft)	Total Length of Core (ft)	Deg. LAT (NAD 27)	Deg. LON (NAD 27)	Reference Number
Oj23-06	KHV-88	REB	38	19.5	38.7219	075.0401	20
Oj23-07	KHV-89R1	REB	33.6	11.1	38.7187	075.0344	20
Oj23-08	KHV-89R2	REB	33.5	14.3	38.7187	075.0345	20
Oj24-01	KHV-40	REB	30.5	19.7	38.7269	075.0272	18
Oj24-02	KHV-41	REB	29.9	19.9	38.7225	075.0211	18
Oj24-03	KHV-87	REB	37.8	19.4	38.7267	075.0329	20
Oj24-04	KHV-90	REB	26.5	15.3	38.7211	075.0284	20
Oj32-01	KHV-32	REB	35.8	8	38.7135	075.0597	18
Oj33-01	KHV-37	REB	42.2	18	38.7152	075.0369	18
Oj34-01	KHV-91	REB	47.5	16.2	38.7138	075.0328	20
Oj34-02	KHV-92R1	REB	33	11.6	38.7152	075.0232	20
Oj34-03	KHV-92R2	REB	33	11	38.7152	075.0234	20
Oj41-36	JCK D1 81	REB	10	34.8	38.6917	075.0700	12, 14
Oj42-01	JCK D2 81	REB	20	37.2	38.6917	075.0633	12, 14
Oj42-02	JCK D3 81	REB	30	38	38.6917	075.0567	12, 14
Oj43-01	KHV-34	REB	41.7	20	38.6858	075.0428	18
Oj52-01	KHV-31	REB	27.4	20	38.6747	075.0581	18
Oj54-01	KHV-39	REB	49.7	17.7	38.6783	075.0181	18
Ok42-01	DGS97-28	OCL	53	5.46	38.6972	074.9752	16
Ok42-03	DGS97-54	OCL	43.61	4.2	38.6969	074.9753	16
Ok52-01	DGS97-26	OCL	51.5	12.17	38.6709	074.9724	16
Ok52-02	DGS97-27	OCL	48	10.3	38.6827	074.9727	16
Ok52-03	DGS97-60.1	OCL	41.02	7.7	38.6825	074.9725	16
Ok52-04	DGS97-60.2	OCL	40.6	5	38.6828	074.9725	16
Pj12-02	JCK E1 81	REB	10	29	38.6625	075.0650	12, 14
Pj12-03	JCK E2 81	REB	23	22	38.6625	075.0583	12, 14
Pj12-04	JCK E3 81	REB	30	20.9	38.6625	075.0500	12, 14
Pj13-01	KHV-1	REB	29	11	38.6625	075.0447	6
Pj13-02	KHV-2	REB	27	16	38.6567	075.0444	6
Pj13-03	KHV-3	REB	31	20	38.6550	075.0458	6
Pj13-04	SDK 7	REB	35	8.9	38.6639	075.0375	3
Pj14-01	KHV-95	REB	49.6	14.4	38.6526	075.0185	21
Pj14-02	KHV-33	REB	31.6	18.6	38.6500	075.0305	18
Pj15-01	KHV-38	REB	48.6	17.4	38.6553	075.0146	18
Pj15-02	KHV-93	REB	53.9	19.7	38.6582	075.0116	21
Pj15-03	KHV-94 R1	REB	57.1	10.0	38.6553	075.0045	21
Pj15-04	KHV-94 R2	REB	58.3	16.6	38.6555	075.0044	21
Pj22-03	JCK F1 81	REB	15	15.1	38.6458	075.0633	12, 14
Pj22-04	JCK F2 81	REB	22	23	38.6458	075.0583	12, 14
Pj22-05	JCK F3 81	REB	30	18.6	38.6458	075.0500	12, 14
Pj23-01	KHV-4	REB	27	15.2	38.6408	075.0442	6
Pj24-01	SDK 9	REB	43	22.3	38.6486	075.0208	3
Pj24-02	KHV-36	REB	40.4	14	38.6389	075.0278	18
Pj24-03	KHV-97	REB	45.9	18.2	38.6446	075.0186	21
Pj25-01	SDK 8	REB	46	5.9	38.6444	075.0083	3

Appendix A (cont.)

DGS ID	Local ID	Quad	Water Depth(ft)	Total Length of Core (ft)	Deg. LAT (NAD 27)	Deg. LON (NAD 27)	Reference Number
Pj25-02	KHV-42	REB	42.8	17.4	38.6403	075.0044	18
Pj25-03	KHV-96	REB	51.8	17.5	38.6499	075.0081	21
Pj25-04	KHV-98 R1	REB	49.5	11.0	38.6446	075.0045	21
Pj25-05	KHV-98 R2	REB	49.3	17.6	38.6445	075.0045	21
Pj25-06	KHV-99 R1	REB	45.6	12.8	38.6418	075.0116	21
Pj25-07	KHV-99 R2	REB	45.2	18.7	38.6418	075.0115	21
Pj25-08	KHV-100	REB	45.0	19.4	38.6363	075.0080	21
Pj25-09	KHV-101	REB	44.4	19.3	38.6335	075.0046	21
Pj33-01	KHV-56	REB	30.9	19.8	38.6328	075.0500	18
Pj34-01	KHV-59	BEB	46.2	20.2	38.6169	075.0200	19
Pj35-01	KHV-57	REB	39.9	19.7	38.6253	075.0166	18
Pj35-02	KHV-102	REB	41.7	19.3	38.6307	075.015	21
Pj42-12	JCKIRI381	BEB	20	16.4	38.6135	075.0511	10
Pj42-13	JCKIRI481	BEB	9	10	38.6064	075.0550	10
Pj42-14	KHV-17	BEB	20.4	20	38.6119	075.0511	11
Pj42-15	KHV-18	BEB	14.5	20	38.6039	075.0519	11
Pj42-16	KHV-19	BEB	23	20	38.6132	075.0567	11
Pj42-17	KHV-20	BEB	16.6	9.8	38.6067	075.0569	11
Pj42-18	KHV-22	BEB	48.2	20	38.6081	075.0617	11
Pj42-19	KHV-23	BEB	48.8	20	38.6089	075.0617	11
Pj42-26	B8	BEB	21	100	38.6089	075.0428	1
Pj42-27	B9	BEB	20	120.5	38.6089	075.0513	1
Pj42-28	B6	BEB	35.5	110.3	38.6081	075.0513	1
Pj42-29	B7	BEB	33.5	112	38.6078	075.0512	1
Pj43-01	JCKIRI281	BEB	13	7.4	38.6047	075.0486	10
Pj43-02	JCKIRI181	BEB	30	19.7	38.6094	075.0486	10
Pj43-03	KHV-46	BEB	40.7	18.6	38.6123	075.0382	17, 18
Pj43-04	KHV-103 R1	BEB	21.2	8.8	38.6114	075.0499	21
Pj43-05	KHV-103 R2	BEB	21.3	13.6	38.6114	075.0499	21
Pj43-06	KHV-103 R3	BEB	21.3	15.8	38.6114	075.0499	21
Pj43-07	KHV-104 R1	BEB	26.9	14.8	38.6061	075.0446	21
Pj43-08	KHV-104 R2	BEB	26.2	19.1	38.6062	075.0446	21
Pj43-09	KHV-105 R1	BEB	28.1	7.4	38.6089	075.0475	21
Pj43-10	KHV-105 R2	BEB	28.3	18.8	38.6089	075.0474	21
Pj44-01	KHV-107	BEB	41.7	18.4	38.6061	075.0187	21
Pj45-01	DGS92 2	BEB	41.1	18	38.6064	075.0083	16
Pj45-02	KHV-60	BEB	46.2	18.3	38.6138	075.0028	19
Pj45-03	KHV-106	BEB	42.3	19.0	38.6142	075.0117	21
Pj45-04	KHV-108	BEB	41.6	16.6	38.6060	075.0011	21
Pj45-05	KHV-109	BEB	44.6	16.4	38.6033	075.0082	21
Pj52-04	JCK G1 81	BEB	14	21.6	38.5917	075.0578	12, 14
Pj52-05	JCK G2 81	BEB	25	28.4	38.5917	075.0500	12, 14
Pj53-01	JCK G3 81	BEB	32	26.2	38.5917	075.0417	12, 14
Pj54-01	KHV-113	BEB	48.1	20.0	38.5895	075.0187	21
Pj55-01	KHV-52	REB	39	20.5	38.5997	075.0086	18

Appendix A (cont.)

DGS ID	Local ID	Quad	Water Depth(ft)	Total Length of Core (ft)	Deg. LAT (NAD 27)	Deg. LON (NAD 27)	Reference Number
Pj55-02	KHV-110	BEB	43.0	16.8	38.5978	075.0151	21
Pj55-03	KHV-111	BEB	45.0	19.3	38.5979	075.0012	21
Pj55-04	KHV-112	BEB	45.5	19.1	38.5923	075.0083	21
Pj55-05	KHV-114	BEB	43.0	19.8	38.5868	075.0013	21
Pk11-01	SDK 10	OCL	62	10	38.6617	074.9883	3
Pk12-01	DGS92 8	OCL	60.1	18	38.6575	074.9706	16
Pk22-01	DGS97-59	OCL	55.1	18.5	38.6381	074.9706	16
Pk31-01	KHV-53	FHN	42.66	20	38.6217	074.9983	18
Pk32-01	DGS97-25	FHN	60	9	38.6233	074.9698	16
Pk32-02	DGS97-53	FHN	54.78	17.4	38.6231	074.9697	16
Pk42-01	DGS97-24	FHN	56	7.42	38.6083	074.9672	16
Pk42-02	DGS97-52	FHN	49.11	18.5	38.6083	074.9672	16
Pk51-01	DGS92 7	FHN	44.5	20	38.5861	074.9892	16
Pk52-01	DGS97-23	FHN	59	7.8	38.5936	074.9669	16
Pk52-02	DGS97-51	FHN	50.35	17.1	38.5936	074.9669	16
Pk55-01	DGS97-46	FHN	56.33	20	38.5839	074.9239	16
Pl41-01	DGS92 14	FHN	72.5	20	38.6092	074.9039	16
Pl51-01	DGS92 13	FHN	64.2	14	38.5844	074.9064	16
Pl51-02	DGS97-56	FHN	60.45	19.5	38.5903	074.9135	16
Pl52-01	DGS97-16	FHN	86	1.75	38.5843	074.8865	16
Pl53-01	DGS97-17	SOM	83	2.58	38.5852	074.8689	16
Pl55-01	DGS92 15	SOM	82.9	2.5	38.5833	074.8403	16
Pl55-02	DGS92 15A	SOM	82.9	1.2	38.5833	074.8403	16
Qj12-01	JCK H1 81	BEB	13	7.5	38.5750	075.0553	12, 14
Qj13-01	KHV-5	BEB	20	20	38.5811	075.0383	6
Qj13-02	KHV-6	BEB	22	17.5	38.5708	075.0375	6
Qj13-03	JCK H2 81	BEB	23	21.5	38.5750	075.0483	12, 14
Qj13-04	JCK H3 81	BEB	32	25.6	38.5750	075.0367	12, 14
Qj15-01	KHV-61	BEB	46.2	17.7	38.5815	075.0163	19
Qj15-02	KHV-62	BEB	48.8	17.2	38.5758	075.0011	19
Qj15-03	KHV-115	BEB	44.0	18.1	38.5814	075.0084	21
Qj23-01	KHV-7	BEB	23	19	38.5650	075.0361	6
Qj24-01	SDK 13	BEB	30	9.8	38.5515	075.0319	3
Qj24-02	SDK 16	BEB	33	20.4	38.5650	075.0300	3
Qj24-03	DGS92 3	BEB	39.8	17	38.5525	075.0206	16
Qj24-04	KHV-49	BEB	35.7	19.5	38.5598	075.0187	17, 18
Qj25-01	SDK 15	BEB	38	10.7	38.5528	075.0056	3
Qj32-26	JCK I1 81	BEB	8	23.6	38.5400	075.0503	12, 14
Qj33-01	JCK I2 81	BEB	18	18.6	38.5400	075.0467	12, 14
Qj33-02	JCK I3 81	BEB	29	28.4	38.5400	075.0367	12, 14
Qj33-03	KHV-44	BEB	28.1	20.2	38.5500	075.0464	17, 18
Qj34-01	KHV-8	BEB	30	20	38.5467	075.0325	6
Qj35-01	KHV-63	BEB	48.7	17.9	38.5342	075.0008	19
Qj35-02	KHV-64	BEB	51	19.7	38.5342	075.0103	19
Qj35-03	KHV-50	BEB	23.6	18	38.5440	075.01233	17, 18

Appendix A (cont.)

DGS ID	Local ID	Quad	Water Depth(ft)	Total Length of Core (ft)	Deg. LAT (NAD 27)	Deg. LON (NAD 27)	Reference Number
Qj43-01	KHV-47	BEB	41.2	18	38.5172	075.0339	17, 18
Qj45-01	KHV-65	BEB	51	19.8	38.5250	075.0089	19
Qj52-18	JCK J1 81	BEB	10	22.2	38.5135	075.05167	12, 14
Qj53-01	JCK J2 81	BEB	20	26.2	38.5135	075.0467	12, 14
Qj53-02	JCK J3 81	BEB	29	20.3	38.5135	075.0350	12, 14
Qj55-01	KHV-66	BEB	44.1	17.9	38.5163	075.0050	19
Qj55-02	KHV-67	BEB	47	19.5	38.5061	075.0115	19
Qj55-03	KHV-68	BEB	40.5	18.9	38.5017	075.0015	19
Qk11-01	DGS97-22	FHN	51	9.8	38.5793	074.9921	16
Qk11-02	DGS97-50	FHN	45.55	19	38.5794	074.9919	16
Qk12-01	DGS97-21	FHN	50	8	38.5803	074.9804	16
Qk12-02	DGS97-49	FHN	45.72	20	38.5806	074.9797	16
Qk12-03	DGS97-48.1	FHN	48.8	14	38.5806	074.9669	16
Qk12-04	DGS97-48.2	FHN	48.52	16	38.5803	074.9669	16
Qk12-05	DGS97-20	FHN	54	6.42	38.5802	074.9669	16
Qk13-01	DGS92 9	FHN	56.8	20	38.5756	074.9533	16
Qk14-01	DGS97-19	FHN	61	1.75	38.5823	074.9379	16
Qk14-02	DGS97-47	FHN	55.5	19.5	38.5825	074.9378	16
Qk21-01	DGS92 6	FHN	49.6	20	38.5572	074.9889	16
Qk21-02	SDK 14	FHN	47	6.2	38.5569	074.9972	3
Qk33-01	DGS97-58	FHN	52.25	18.3	38.5342	074.9619	16
Qk33-02	DGS97-57	FHN	52	20	38.5492	074.9631	16
Qk43-01	DGS92 10	FHN	56	11	38.5178	074.9500	16
Qk51-01	KHV-54	REB	40.3	19.8	38.5075	074.9869	18
Qk53-01	DGS97-11	FHN	54	2.5	38.5034	074.9603	16
Qk53-02	DGS97-39	FHN	46.78	19.3	38.5033	074.9600	16
Ql51-01	DGS97-10	FHN	62	6.42	38.5102	074.9116	16
Ql51-02	DGS97-38	FHN	54.23	19.5	38.5097	074.9115	16
Rj12-01	JCK K1 81	ASB	19	33.8	38.4967	075.0500	12, 14
Rj13-01	JCK K2 81	ASB	20	26.1	38.4967	075.0467	12, 14
Rj13-02	JCK K3 81	ASB	32.8	20.3	38.4967	075.0350	12, 14
Rj14-01	KHV-72	ASB	42.4	20.2	38.4867	075.0217	19
Rj15-01	KHV-69	ASB	40	19.8	38.4911	075.0078	19
Rj15-02	KHV-51	ASB	36.3	17.5	38.4987	075.0102	17, 18
Rj23-01	KHV-70	ASB	41.6	20.1	38.4744	075.0403	19
Rj23-02	KHV-45	ASB	36.2	16.1	38.4713	075.0374	17, 18
Rj24-01	KHV-73	ASB	43.5	19.4	38.4764	075.0250	19
Rj24-02	KHV-48	ASB	34.3	19.5	38.4698	075.0200	17, 18
Rj25-01	KHV-76	ASB	43	20.4	38.4686	075.0164	19
Rj25-02	KHV-79	ASB	51.5	19.7	38.4825	075.0017	19
Rj33-01	CORE13	ASB	29.9	10	38.4519	075.0336	7
Rj33-02	JCK L1 81	ASB	14	13.5	38.4500	075.0486	12, 14
Rj33-03	JCK L2 81	ASB	19	21.3	38.4500	075.0450	12, 14
Rj33-04	JCK L3 81	ASB	30	19.4	38.4500	075.0350	12, 14
Rj33-05	KHV-71	ASB	40.7	20.3	38.4633	075.0367	19

Appendix A (cont.)

DGS ID	Local ID	Quad	Water Depth(ft)	Total Length of Core (ft)	Deg. LAT (NAD 27)	Deg. LON (NAD 27)	Reference Number
Rj33-06	8-3	ASB	28	16	38.4530	075.0360	15
Rj34-01	KHV-74	ASB	41.5	19.9	38.4633	075.0228	19
Rj34-02	8-6	ASB	35	20	38.4570	075.0200	15
Rj35-01	KHV-77	ASB	38	19.9	38.4550	075.0146	19
Rj35-02	KHV-78	ASB	41.4	19.9	38.4658	075.0083	19
Rj35-03	KHV-80	ASB	49.1	19.5	38.4592	075.0044	19
Rk11-01	DGS92 5	FWS	46.4	19.5	38.4903	074.9875	16
Rk13-01	DGS97-13	FWS	64	4.4	38.4890	074.9587	16
Rk13-03	DGS97-41.2	FWS	58.7	19	38.4889	074.9586	16
Rk13-04	DGS97-40	FWS	52.9	20	38.4956	074.9600	16
Rk21-01	DGS92 4	FWS	51	160	38.4686	074.9858	16
Rk21-02	KHV-75	FWS	38.3	20.1	38.4797	074.9947	19
Rk23-01	DGS97-14	FWS	68	2.42	38.4812	074.9585	16
Rk23-02	DGS97-14.1	FWS	66	3.42	38.4813	074.9586	16
Rk23-03	DGS97-14.2	FWS	66	4.75	38.4813	074.9586	16
Rk23-04	DGS97-42	FWS	61.08	19.9	38.4815	074.9586	16
Rk23-05	DGS97-43	FWS	54.81	18.9	38.4719	074.9572	16
Rk25-01	DGS97-55.1/55.2	FWS	29.51	17	38.4722	074.9197	16
Rk25-02	DGS97-55.2	FWS	29.46	8.5	38.4722	074.9197	16
Rk31-01	3-12	FWS	41	18.6	38.4508	074.9902	15
Rk31-02	3-1	FWS	45	18	38.4570	074.9840	15
Rk31-03	3-2	FWS	33	19	38.4590	074.9920	15
Rk31-04	3-4	FWS	40	20	38.4640	074.9930	15
Rk31-05	3-11	FWS	40	17.6	38.4560	074.9900	15
Rk33-01	DGS92 11	FWS	57.6	10.8	38.4589	074.9519	16
Rk34-02	DGS97-32	FWS	29.42	18.5	38.4612	074.9302	16
Rk35-01	DGS97-2	FWS	46	1.5	38.4611	074.9225	16
Rk35-02	DGS97-31	FWS	23.45	19.7	38.4615	074.9281	16
Rk35-03	DGS97-30	FWS	41.45	20	38.4611	074.9225	16
Rk35-04	DGS97-29	FWS	42.35	20.2	38.4611	074.9172	16
Rk35-05	DGS97-3	FWS	28	3.1	38.4612	074.9225	16
Rk44-01	DGS97-4	FWS	34	2.08	38.4622	074.9338	16
Rl11-01	DGS97-37	FWS	47.3	19.4	38.4969	074.9108	16
Rl21-01	DGS97-5	FWS	43	3.08	38.4694	074.9086	16
Rl21-02	DGS97-6	FWS	44	1.83	38.4749	074.9089	16
Rl21-03	DGS97-8	FWS	46	11.5	38.4805	074.9100	16
Rl21-04	DGS97-36	FWS	38.4	19	38.4806	074.9100	16
Rl21-05	DGS97-35	FWS	42.16	20	38.4778	074.9097	16
Rl21-06	DGS97-34	FWS	37.55	20	38.4750	074.9086	16
Rl21-07	DGS97-33.1	FWS	36.48	16	38.4692	074.9089	16
Rl21-08	DGS97-33.2	FWS	36.11	6.5	38.4692	074.9086	16
Rl25-01	DGS92 16	SOU	75.5	11.8	38.4744	074.8403	16
Rl31-01	DGS92 12	FWS	53.9	16.2	38.4561	074.9050	16

Appendix B

Lithologic and Resource Rating Descriptions for Cores from the Atlantic Offshore, Delaware (DGS Offshore Core Inventory)

E – Excellent G – Good F – Fair P – Poor

DGS ID	Core Length (ft)	Lithologic Category (top 5 ft)	Lithologic Category (top 5 ft/rest of core)	Thickness (ft) top 5 ft/rest of core	Thickness Symbol	Lithologic Rating	Resource Rating
Mj32-01	5.9	5L	L/l	5/0.9	10	10L	F
Mj41-01	11.5	5S	S/S	5/6.5	15	15S	E
Mj41-02	0.5	0.5s	s	0.5	1	1s	P
Mj41-03	0.75	0.75l	l	0.75	1	1l	P
Mj41-04	0.6	0.6s	s	0.6	1	1s	P
Mj45-01	0.5	0.5l	l	0.5	1	1l	P
Mj51-01	15.75	5S	S/S	5/10.75	20	20S	E
Mk31-01	0.25	0.25m	m	0.25	1	1m	P
Ni35-12	14.1	5S	S	5/9.1	15	15S	E
Ni35-13	20.3	3s	s/M (S)	3/6.8 (10.5)	3/10 (10)	3s/10M 10S	F
Nj23-01	0.5	0.5s	s	0.5	1	1s	P
Nj23-02	0.8	0.8s	s	0.8	1	1s	P
Nj23-03	3.5	3.5s	s	3.5	4	4s	F
Nj31-01	29.5	5S	S/L (M)	5/13.9 (10)	5/15 (10)	5S 15L 10M	G
Nj33-01	0.5	0.5s	s	0.5	1	1s	P
Nj33-03	0.33	0.33s	s	0.33	1	1s	P
Nj51-03	32.8	5S	S/M (s)	5/26.2 (1.6)	5/30 (2)	5S 30M 2s	G
Nj51-04	26.2	3l	l/M (L)	3/17 (6.2)	3/20 (10)	3l/20M 10L	P
Nj51-05	27.6	1.5s	s/M (L) S	1.5/11.3 (5) 11	1.5/15 (5) 15	1.5s/15M 5L 15S	P
Nj52-01	16	5L	L/L (S)	5/6 (4)	5/10 (4)	15L 4s	F
Nj52-02	5.9	5L	L	5/1	10	10L	F
Nj52-03	14.1	3s	s	3.28	3	3s	F
Nj54-01	28.7	5L	l/M (L)	5/15 (8.7)	5/15 (10)	5L 15M 10L	P
Nk32-01	1.1	1.1l	l	1.1	1	1l	P
Nk32-02	1.25	1.25m	m	1.25	1	1m	P
Nk33-01	29	5M	M/M (l) m(g) s	5/14 (2.3) 3.4 (4.3)	5/20 (4)	25M 4s	P
Nk41-01	0.3	0.3m	m	0.3	1	1m	P
Nk41-02	27.5	5L	L/L	5/22.5	30	30L	F
Nk42-01	29.5	5L	L/L	5/24.5	30	30L	F
Oj12-01	15.2	5L	L/L (g)	5/9.25 (1)	5/10 (1)	15L 1g	F
Oj13-01	20	5L	L	5/15	20	20L	F
Oj13-02	20	5L	L	5/15	20	20L	F
Oj13-03	4.6	5l	l	4.6	5	5l	F
Oj13-04	16.5	5L	L	5/11.5	20	20L	F
Oj13-05	15.8	5L	L	5/10.8	20	20L	F
Oj13-06	17	5L	L	5/12	20	20L	F
Oj21-09	32.8	1s	s/M	1/32	1/35	1s/35M	P
Oj21-10	30	5M	M	5/25	30	30M	P
Oj22-01	13.6	1.5l	l/M (L)	1.5/5.6 (5.5)	1.5/10 (5)	1.5l/10M 5L	P

Appendix B (cont.)

DGS ID	Core Length (ft)	Lithologic Category (top 5 ft)	Lithologic Category (top 5 ft/rest of core)	Thickness (ft) top 5 ft/rest of core	Thickness Symbol	Lithologic Rating	Resource Rating
Oj22-02	26.2	5L	L	5/21.2	30	30L	F
Oj23-01	16	5L	L	5/11	20	20L	F
Oj23-02	16	1s	s/L	1/15	1/15	1s/15L	F
Oj23-03	20	5S	S/l (S)	5/3.4 (11.6)	5/3 (15)	5S 3l 15S	G
Oj23-04	20	5L	L	5/15	20	20L	F
Oj23-05	17.8	5L	L	5/12.8	20	20L	F
Oj23-06	19.5	5L	L	5/14.5	20	20L	F
Oj23-07	11.1	5L	L	5/6.1	15	15L	F
Oj23-08	14.3	5L	L/L s	5/7 (2.3)	5/10 (2)	15L 2s	F
Oj24-01	19.7	5L	L	5/14.7	20	20L	F
Oj24-02	19.9	5S	S/S (l)	5/11.3 (3.6)	20 (4)	20S 4l	E
Oj24-03	19.4	5L	L	5/14.4	20	20L	F
Oj24-04	15.3	3s	s/L	3/12.3	3/15	3s/15L	F
Oj32-01	8	5L	L/L (s)	5/0.8 (2.2)	5/1 (2)	10L 2s	F
Oj33-01	18	5S	S	5/13	20	20S	E
Oj34-01	16.2	5L	L/L (s)	5/7.2 (4)	5/10 (4)	15L 4s	F
Oj34-02	11.6	5L	L	5/6.6	15	15L	F
Oj34-03	11	5L	L	5/6	15	15L	F
Oj41-36	34.8	5L	L/l (S) M	5/1.5 (5) 23.2	5/2 (5) 25	10L 5S 25M	F
Oj42-01	37.2	2.7s	s/M	2.7/34.5	3/35	3s/35M	F
Oj42-02	38	5M	M/M (l)	5/29.4 (3.6)	5/30 (4)	35M 4l	P
Oj43-01	20	2.5m	m/s (M)	2.5/1.7 (15.8)	2.5/2 (20)	2.5m/2s 20M	P
Oj52-01	20	5L	L	5/15	20	20L	F
Oj54-01	17.7	5L	L/l (m) S	5/2.7 (2) 8	5/3 (2) 10	10L 2m 10S	F
Ok42-01	5.46	5L	L	5.46	10	10L	F
Ok42-03	4.2	4l	l	4.2	4	4l	F
Ok52-01	12.17	5L	L	5/7.17	15	15L	F
Ok52-02	10.3	5L	L/l (m)	5/1.3 (4)	5/1 (4)	10L 4m	F
Ok52-03	7.7	5M	M/m (l)	5/1.3 (1.4)	5/1 (1)	10M 1l	P
Ok52-04	5	5L	L	5	5	5L	F
Pj12-02	29	5M	M	5/24	30	30M	P
Pj12-03	22	5L	L	5/17	25	25L	F
Pj12-04	20.9	5S	S/s (L)	5/2 (14)	5/2 (15)	10S 15L	G
Pj13-01	11	5S	S/s (m)	5/2 (4)	5/2 (4)	10S 4m	G
Pj13-02	16	5L	L/l (M)	5/1 (9)	5/1 (10)	10L 10M	F
Pj13-03	20	5M	M/m (L)	5/3 (12)	5/3 (15)	10M 15L	P
Pj13-04	8.9	5L	L	5/3.9	10	10L	F
Pj14-01	14.4	3.4s	s/M (s)	3.4/8.1 (2.9)	3/10 (3)	3s/10M 3s	F
Pj14-02	18.6	5S	S	5/13.6	20	20S	E
Pj15-01	17.4	5L	L/L (S)	5/5 (7.4)	5/5 (10)	10L 10S	F
Pj15-02	19.7	3.7l	l/M	3.7/16	3/20	3l/20M	P
Pj15-03	10.0	5S	S/l (s)	5/2 (3)	5/2 (3)	5S 2l 3s	G
Pj15-04	16.6	5S	S/l (S)	5/2 (9.6)	5/2 (10)	5S 2l 10S	G
Pj22-03	15.1	5S	S/s (m)	5/3.4 (1)	5/3 (1)	10S 1m	G
Pj22-04	23	5S	S/L (s)	5/14.1 (3.9)	5/15 (4)	5S 15L 4s	G
Pj22-05	18.6	5S	S/s (M) l	5/2.7 (7)	5/3 (10) 4	10S 10M	G

Appendix B (cont.)

DGS ID	Core Length (ft)	Lithologic Category (top 5 ft)	Lithologic Category (top 5 ft/rest of core)	Thickness (ft) top 5 ft/rest of core	Thickness Symbol	Lithologic Rating	Resource Rating
				3.4		4l	
Pj23-01	16.2	5S	S/s (M) s	5/1 (5.2) 4	5/1 (5) 4	10S 5M 4s	G
Pj24-01	22.3	3.6s	s/M	3.6/18.7	4/20	4s/20M	F
Pj24-02	14	2s	s/l (M)	2/2 (9)	2/2 (10)	2s/2l 10M	F
Pj24-03	18.2	1.6s	s/l (gS) S	1.6/2.9 (3) 10.7	2/3 (3) 15	2s/3l 3gS 15S	F
Pj25-01	5.9	5S	S	5/1.9	5/2	10S	G
Pj25-02	17.4	5S	S	5/12	20	20S	E
Pj25-03	17.5	5S	S/S (gS)	5/7 (5.5)	5/10 (10)	15S 10gS	E
Pj25-04	11.0	5S	S/S (gS)	5/1.5 (4.5)	5/2 (5)	10S 5gS	E
Pj25-05	17.6	5S	S/s (gS) S	5/1.5 (5.5) 4.6	5/2 (10) 5	10S 10gS 5S	E
Pj25-06	12.8	5gS	gS/gS	5/7.8	5/10	15gS	E
Pj25-07	18.7	5gS	gS/gS	5/13.7	5/15	20gS	E
Pj25-08	19.4	5gS	gS/S (gS)	5/10 (4.4)	5/10 (4)	5gS 10S 4gS	E
Pj25-09	19.3	4.8gS	gS/S (gS)	4.8/5.2 (9.3)	5/5 (10)	5gS 5S 10gS	E
Pj33-01	19.8	1.5m	m/S (L)	1.5/8.5 (9.8)	1.5/10 (10)	1.5m/10S 10L	F
Pj34-01	20.2	5S	S/M	5/15.2	5/15	5S 15M	G
Pj35-01	19.7	5L	L	5/14.7	5/15	20L	F
Pj35-02	19.3	5S	S/S (gS)	5/4.1 (10.2)	5/4 (10)	10S 10gS	E
Pj42-12	16.4	5S	S/s (M)	5/4.8 (6.6)	5/5 (10)	10S 10M	G
Pj42-13	10	5S	S/S	5/5	10	10S	G
Pj42-14	20	5L	L/L (M)	5/6.5 (9.5)	5/10 (10)	15L 10M	F
Pj42-15	20	5L	L/L (m)	5/12.5 (2.5)	5/15 (3)	20L 3m	F
Pj42-16	20	5M	M/M	5/15	20	20M	P
Pj42-17	9.8	5L	L/l	5/4.8	10	10L	F
Pj42-18	20	5M	M/M	5/15	20	20M	P
Pj42-19	20	5M	M/M	5/15	20	20M	P
Pj42-26	100	5L	L/L (M) L	5/12 (32) 30	20 (35) 30	20L 35M 30L	F
Pj42-27	120.5	5S	S/S (M) L	5/15 (43.5) 37	20 (45) 40	20S 45M 40L	E
Pj42-28	110.3	5M	M/M (l) S	5/44.5 (4) 21.3	50 (4) 25	50M 4l 25S	P
Pj42-29	112	5M	M/M (L) S	5/47 (9) 18	55 (10) 20	55M 10L 20S	P
Pj43-01	7.4	5S	S/s	5/2.4	10	10S	G
Pj43-02	19.7	5L	L/L	5/14.2 (1.5)	5/15 (2)	20L 2m	F
Pj43-03	18.6	2.5l	l/S (M) l	2.5/6.1 (5.9) 4.1	3/10 (10) 4	3l/10S 10M 4l	F
Pj43-04	8.8	5S	S/s	5/3.8	5/4	10S	G
Pj43-05	13.6	5S	S/s (L)	5/3 (5.6)	5/3 (10)	10S 10L	G
Pj43-06	15.8	5S	S/s (L)	5/3 (7.8)	5/3 (10)	10S 10L	G
Pj43-07	14.8	5S	S/s (L)	5/0.3 (9.3)	5/10	5S 10L	G
Pj43-08	19.1	5S	S/s (L)	5/0.3 (13.8)	5/15	5S 15L	G
Pj43-09	7.4	5L	L/l	5/2.4	10	10L	F
Pj43-10	18.8	5L	L/L (m)	5/9.7 (4.1)	5/10 (4)	15L 4m	F

Appendix B (cont.)

DGS ID	Core Length (ft)	Lithologic Category (top 5 ft)	Lithologic Category (top 5 ft/rest of core)	Thickness (ft) top 5 ft/rest of core	Thickness Symbol	Lithologic Rating	Resource Rating
Pj44-01	18.4	5S	S/S (L)	5/5.9 (7.5)	5/10 (10)	15S 10L	E
Pj45-01	18	3s	s/gS (S) l	3/5 (8) 2	3/5 (10) 2	3s/5gS 10S 2l	E
Pj45-02	18.3	5S	S/S	5/13.3	20	20S	E
Pj45-03	19.0	2gS	gS/S	2/17	2/20	2gS/20S	E
Pj45-04	16.6	5S	S/gS (S)	5/3.1 (6.6)	5/5 (10)	5S 5gS 10S	E
Pj45-05	16.4	2.1gS	gS/s (gS) S	2.1/2.6 (5.3) 6.4	2/3 (5) 10	2gS/3s 5gS 10S	E
Pj52-04	21.6	5S	S/l (S)	5/1.6 (14)	5/2 (15)	5S 2l 15S	G
Pj52-05	28.4	5L	L/L (S)	5/5.2 (18.2)	5/5 (20)	10L 20S	F
Pj53-01	26.2	2.5s	s/M	2.5/23.5	3/25	3s/25M	F
Pj54-01	20.0	5S	S/S	5/15	5/15	20S	E
Pj55-01	20.5	5S	S/S	5/15.5	20	20S	E
Pj55-02	16.8	5S	S/S (M)	5/5 (6.8)	5/5 (10)	10S 10M	G
Pj55-03	19.3	5S	S/S (l)	5/10 (4.3)	5/10 (4)	15S 4l	E
Pj55-04	19.1	5gS	gS/gS (M) s	5/0.5 (9.4) 4.2	5/1 (10) 4	10gS 10M 4s	G
Pj55-05	19.8	5L	L/l (gS) S (l)	5/0.2 (4.8) 5 (4.8)	5/(5) 5 (5)	5L 5gS 5S 5L	F
Pk11-01	10	2.8l	l/S (g)	2.8/6.3 (0.9)	3/10 (1)	3l/10S 1g	F
Pk12-01	18	5L	L (s)	5/9 (4)	5/10 (4)	15L 4s	F
Pk22-01	18.5	3.5s	s/G (S)	3.5/5 (10)	3.5/5 (10)	3.5s/5G 10S	F
Pk31-01	20	5L	L/L	5/15	20	20L	F
Pk32-01	9	5S	S/s	5/4	10	10S	G
Pk32-02	17.4	3.2s	s/gS (S)	3.2/4.7 (9.5)	3/5 (10)	3s/5gS 10S	E
Pk42-01	7.42	5S	S/s	5/2.5	10	10S	G
Pk42-02	18.5	5S	S/S	5/13.5	20	20S	E
Pk51-01	20	5S	S/S	5/15	20	20S	E
Pk52-01	7.8	5S	S/s	5/3	10	10S	G
Pk52-02	17.1	5S	S/S	5/12	20	20S	E
Pk55-01	20	5S	S/s (gS) S	5/5.8 (4.2) 5	5/10 (4) 5	15S 4gS 5S	E
Pl41-01	20	5M	M/M	5/15	20	20M	P
Pl51-01	14	5S	S/S	5/9	15	15S	E
Pl51-02	19.5	5S	S/S	5/14.5	20	20S	E
Pl52-01	1.75	2m	m	2	2	2m	P
Pl53-01	2.58	3m	m	3	3	3m	P
Pl55-01	2.5	3s	s	3	3	3s	F
Pl55-02	1.2	1s	s	1	1	1s	P
Qj12-01	7.5	5L	L/l	5/2.5	10	10L	F
Qj13-01	20	5L	L/l (s) M	5/1.5 (4) 9.5	10 (4) 10	10L 4s 10M	F
Qj13-02	17.5	5S	S/s (V) M	5/1 (5) 6.5	5/1 (5) 10	10S 5V 10M	G
Qj13-03	21.5	1s	s/M (l)	1/17 (4)	1/20 (4)	1s/20M 4l	P
Qj13-04	25.6	5S	S/M (L)	5/5.6 (14.9)	5/10 (15)	5S 10M 15L	G
Qj15-01	17.7	5S	S/l (S)	5/3.2 (9.7)	5/3 (10)	5S 3l 10S	G
Qj15-02	17.2	5S	S/S	5/12.2	20	20S	E

Appendix B (cont.)

DGS ID	Core Length (ft)	Lithologic Category (top 5 ft)	Lithologic Category (top 5 ft/rest of core)	Thickness (ft) top 5 ft/rest of core	Thickness Symbol	Lithologic Rating	Resource Rating
Qj15-03	18.1	5S	S/S	5/13.1	5/15	20S	E
Qj23-01	19	5L	L/L (M)	5/5 (8.5)	5/5 (10)	10L 10M	F
Qj24-01	9.8	2.5s	s/L	2.5/7.3	3/10	3s/10L	F
Qj24-02	20.4	5S	S/S (M)	5/8.1 (7.3)	5/10 (10)	15S 10M	E
Qj24-03	17	4s	s/l (M)	4/4.25 (8.75)	4/4 (10)	4s/4l 10M	F
Qj24-04	19.5	5S	S/S (l)	5/11.5 (3)	20 (3)	20S 3l	E
Qj25-01	10.7	5S	S/S	5/5.7	15	15S	E
Qj32-26	23.6	5L	L/L	5/18.6	25	25L	F
Qj33-01	18.6	5L	L/L (S)	5/7.2 (6.4)	15 (10)	15L 10S	F
Qj33-02	28.4	5M	M/M (L)	5/5 (18.4)	10 (20)	10M 20L	P
Qj33-03	20.2	5S	S/S	5/15	20	20S	E
Qj34-01	20	4s	s/M (L)	4/4 (12)	4/4 (15)	4s/4m 15L	F
Qj35-01	17.9	5S	S/S	5/12.9	20	20S	E
Qj35-02	19.7	5L	L/L (S)	5/5.3 (9.4)	5/5 (10)	10L 10S	F
Qj35-03	18	2.5m	m/S	2.5/15.5	2.5/15	2.5m/15S	P
Qj43-01	18	5M	M/S	5/13	5/15	5M 15S	P
Qj45-01	19.8	5L	L/l (S)	5/3 (11.8)	5/3 (15)	10L 15S	F
Qj52-18	22.2	5L	L/L (S)	5/14.8 (2.4)	5/15 (2.5)	20L 2.5s	F
Qj53-01	26.2	5L	L/L (S)	5/13.1 (8.1)	5/13 (10)	20L 10S	F
Qj53-02	20.3	5L	L/l (S)	5/3.8 (11.5)	5/4 (15)	10L 15S	F
Qj55-01	17.9	5S	S/S	5/12.9	20	20S	E
Qj55-02	19.5	5S	S/S (M) l	5/7.4 (5.4) 1.7	5/10 (5) 2	15S 5M 2l	E
Qj55-03	18.9	5S	S/S	5/13.9	20	20S	E
Qk11-01	9.8	5S	S/s	5/4.8	10	10S	G
Qk11-02	19	5S	S/S	5/14	20	20S	E
Qk12-01	8	5S	S/s	5/3	10	10S	G
Qk12-02	20	5L	L/s (M)	5/2.8 (11.7)	5/3 (15)	5L 3s 15M	F
Qk12-03	14	5S	S/s (M)	5/2.6 (5.1)	5/3 (5)	10S 5M	G
Qk12-04	16	4.1gS	gS/S (m)	4.1/7.5 (4.1)	4/10 (4)	4gS/10S 4m	G
Qk12-05	6.42	5S	S/s	5/1.42	10	10S	G
Qk13-01	20	5S	S/S	5/15	20	20S	E
Qk14-01	1.75	1.75s	s	1.75s	2	2s	P
Qk14-02	19.5	4gS	gS/m (S)	4/3 (12.3)	4/3 (15)	4gS/3m 15S	F
Qk21-01	20	5S	S/s (L) S	5/2 (5.25) 7.75	5/2 (5) 10	10S 5L 10S	G
Qk21-02	6.2	1s	s/M	1/5	1/5	1s/5M	P
Qk33-01	18.3	5M	M	5/13.3	20	20M	P
Qk33-02	20	5L	L/l (M) l	5/1 (10.5) 2.5	5/1 (10) 3	10L 10M 3l	F
Qk43-01	11.6	5l	l/M	4.7/6.9	5/10	5l 10M	F
Qk51-01	19.8	3s	s/L	3/16.8	3/20	3s/20L	F
Qk53-01	2.5	2.5s	s	2.5	3	3s	F
Qk53-02	19.3	5S	S/S (l)	5/12.5 (1.8)	5/15 (2)	20S 2l	E
Ql51-01	6.42	5S	S/s	5/1.42	10	10S	G
Ql51-02	19.5	5S	S/s (L) s	5/1.1 (8.9)	5/1 (10) 5	10S 10L	G

DGS ID	Core Length (ft)	Lithologic Category (top 5 ft)	Lithologic Category (top 5 ft/rest of core)	Thickness (ft) top 5 ft/rest of core	Thickness Symbol	Lithologic Rating	Resource Rating
				4.5		5s	
Rj12-01	33.8	2.4l	l/S (L)	2.4/5.6 (25.8)	2.5/5 (25)	2.5l/5S 25L	F
Rj13-01	26.1	5L	L/L (S)	5/11.4 (9.7)	5/15 (10)	20L 10S	F
Rj13-02	20.3	5S	S/S	5/15.3	20	20S	E
Rj14-01	20.2	4.5s	s/l (S)	4.5/1.8 (14.5)	5/2 (15)	5s/2l 15S	F
Rj15-01	19.8	5S	S/s (L) s	5/4.5 (6.5) 3.8	10 (10) 4	10S 10L 4s	G
Rj15-02	17.5	5S	S/S	5/12.5	20	20S	E
Rj23-01	20.1	5S	S/S	5/15.1	20	20S	E
Rj23-02	16.1	5S	S/S	5/11.1	20	20S	E
Rj24-01	19.4	4s	s/l (S)	4/3.7 (11.4)	4/4 (15)	4s/4l 15S	F
Rj24-02	19.5	4.5g	g/S	4.5/15	5/15	5g/15S	F
Rj25-01	20.4	5S	S/L (S)	5.8/5.6 (9)	5/5 (10)	5S 5L 10S	G
Rj25-02	19.7	5M	M/M (l)	5/11 (3.7)	5/15 (4)	20M 4l	P
Rj33-01	10	4l	l/m (l)	4/2.2 (4)	4/2 (4)	4l/2m 4l	F
Rj33-02	13.5	2.4s	s/L	2.4/10.1	2.5/10	2.5s/10L	F
Rj33-03	21.3	5S	S/s (M)	5/3.9 (12.4)	5/4 (15)	10S 15M	G
Rj33-04	19.4	5M	M/l (S)	5/3.4 (11)	5/3 (15)	5M 3l 15S	P
Rj33-05	20.3	5S	S/L (S)	5.8/9.2 (5.3)	6/10 (5)	10S 10L 5S	G
Rj33-06	16	5S	S/M	5.1/10.9	5/15	5S 15M	G
Rj34-01	19.9	4l	l/m (S)	4/3 (12.9)	4/3 (15)	4l/3m 15S	F
Rj34-02	20	4.5s	s/L (S)	4.5/5.1 (10.4)	5/5 (10)	5s/5L 10S	F
Rj35-01	19.9	5S	S/S (L)	5/5 (9.9)	10 (10)	10S 10L	G
Rj35-02	19.9	5S	S/S (L)	5/6.8 (8.1)	15 (10)	15S 10L	E
Rj35-03	19.5	5S	S/s (L) S	5/1.7 (6.2) 6.6	10 (10) 10	10S 10L 10S	G
Rk11-01	19.5	1.4s	s/M (l)	1.4/13.3 (4.8)	1.5/15 (5)	1.5s/15M 5l	P
Rk13-01	4.4	4.4l	l	4.4	5	5l	F
Rk13-03	19	5L	L/S (gS)	5/5.6 (8.4)	5/10 (10)	5L 10S 10gS	F
Rk13-04	20	5S	S/S	5/15	20	20S	E
Rk21-01	15	2s	s/L	2/13	2/15	2s/15L	F
Rk21-02	20.1	5S	S/S (m)	5/13.6 (1.5)	20 (1.5)	20S 1.5m	E
Rk23-01	2.42	1.4l	l/m	1.4/1.02	1.5/1.0	1.5l/1m	P
Rk23-02	3.42	3.4l	l	3.42	3.5	3.5l	F
Rk23-03	4.75	4.75l	l	4.75	5	5l	F
Rk23-04	19.9	1m	m/S (gS)	1/10.7 (8.3)	1/15 (10)	1m/15S 10gS	F
Rk23-05	18.9	5S	S/s (L) s	5/4.2 (6.5) 3.2	10 (10) 3	10S 10L 3s	G
Rk25-01	17	5S	S/S	5/12	20	20S	E
Rk25-02	8.5	5S	S/s	5/3.5	10	10S	G
Rk31-01	18.6	3.3s	s/L (s)	3.3/13.1 (2.2)	3.5/15 (2)	3.5s/15L 2s	F
Rk31-02	18	5S	S/S	5/13	20	20S	E

Appendix B (cont.)

DGS ID	Core Length (ft)	Lithologic Category (top 5 ft)	Lithologic Category (top 5 ft/rest of core)	Thickness (ft) top 5 ft/rest of core	Thickness Symbol	Lithologic Rating	Resource Rating
Rk31-03	19	5S	S/S	5/14	20	20S	E
Rk31-04	20	5S	S/S	5/15	20	20S	E
Rk31-05	17.6	5S	S/S (l)	5/9.2 (3.4)	15 (3.5)	15S 3.5l	E
Rk33-01	10.8	5S	S/S	5/5.8	15	15S	E
Rk34-02	18.5	5S	S/S	5/13.5	20	20S	E
Rk35-01	1.5	1.5l	l	1.5	1.5	1.5l	P
Rk35-02	19.7	5S	S/S	5/14	20	20S	E
Rk35-03	20	5L	L/L	5/15	20	20L	F
Rk35-04	20.2	5S	S/S	5/15.2	20	20S	E
Rk35-05	3.1	3s	s	3.1	3	3s	F
Rk44-01	2.08	2s	s	2.08	2	2s	F
Rl11-01	19.4	5L	L/L	5/14.4	20	20L	F
Rl21-01	3.08	3s	s	3.08	3	3s	F
Rl21-02	1.83	2s	s	1.83	2	2s	P
Rl21-03	11.5	5S	S/S	5/6.5	15	15S	E
Rl21-04	19	5S	S/S	5/14	20	20S	E
Rl21-05	20	5S	S/S (l)	5/12 (3)	20 (3)	20S 3l	E
Rl21-06	20	5S	S/S	5/15	20	20S	E
Rl21-07	18	5S	S/S	5/13	20	20S	E
Rl21-08	5	5S	S	5	5	5S	G
Rl25-01	11.8	5L	L/L	5/6.8	15	15L	F
Rl31-01	16.2	5S	S/s (L)	5/4.5 (6.7)	10 (10)	10S 10L	G

Delaware Geological Survey
University of Delaware
Newark, Delaware 19716